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# Science Needs for Real Time Adaptable Data Products From the Earth Observing System

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# Science Needs for Real Time Adaptable Data Products From the Earth Observing System

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## FOREWORD

Science and Technology Corporation (STC) is pleased to submit this final report entitled "Science Needs for Real Time Adaptable Data Products from The Earth Observing System," which summarizes the work done to date on NASA Contract NAS1-18676, Task 35 entitled "ISES Instrument Definition Support." The goal of the work is to review the potential Earth Observing System (EOS) instruments to advance our knowledge of the Earth system time-dependent processes that impact global climate change research needs. This study considers the parameters to be measured, resolution, characteristics, data reduction algorithms in identifying the best EOS instruments to contribute to the research goals of the EOS program, and the need for real time adaptable products from EOS.

The support and advice of Stephen J. Katzberg and David E. Bowker are gratefully acknowledged.

## TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

## EXECUTIVE SUMMARY

*The unpredictability of discoveries in science is well known. Also the history of science is replete with advances credited to the results from field experiments. To advance understanding of the Earth system requires improved knowledge of the time variant governing processes, and the knowledge of these processes often only comes from real time observations of the changing variables as seen from space. The unpredictability of what is to be measured and at what rate requires flexibility in the observational capability. The Earth Observing System (EOS) will be a major source of observational data during the next 10- to 25-year timeframe. Consequently, to ensure the needed advances in the understanding of the Earth system, real time onboard processing is concluded to be a critical need for EOS.*

Global observations, which range from microphysical processes to solar variability, are prerequisite to advancing the understanding of the Earth's natural system. To quantify the processes and assess the anthropogenic impact on changes of the Earth system require remote observation of these processes from space. The complex Earth system is driven by the Sun's energy, as it moves into the charged spheres (magnetosphere/ionosphere) and then through the thin neutral spheres (mesosphere/stratosphere/troposphere) to the Earth's surface. At the Earth's surface (biosphere/lithosphere/cryosphere), the solar energy fuels biological activity and interacts chemically and thermodynamically with the oceans, ice sheets, and overlying atmosphere. A molecule introduced into the Earth's system from a tropical oceanic latitude does not recognize the scientific disciplines or geopolitical boundaries as it is transported and modified over a middle latitude industrial area to polar regions. This observation illustrates the fact that the processes that govern the Earth system are interdisciplinary and global in perspective.

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Observations of the Earth system from space will provide quantitative data to scientists participating in international endeavors such as the International Geosphere-Biosphere Program (IGBP) and the World Climate Research Program (WCRP). Under these international programs are experiments such as the Global Energy and Water Cycle Experiment (GEWEX), and under these major programs are planned field experiments, which use data derived from spaceborne sensors. Measurements of variables from space are critical for experimental scientists in both the field and laboratories to advance their understanding of the Earth system.

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Measurements from space of all variables that are known to impact the Earth system would be a formidable effort and beyond the scope of any one project. The instruments considered for the NASA Earth Observing System project were analyzed, with the primary criterion being the contribution to advance understanding of global change science. An overwhelming number of global change science topics exist, ranging from solid earth geophysics and geology to outer space. To narrow the scope and enhance the probability of EOS project success a second criterion and central theme of this study was developed. Science topics formulated from the priorities of the U.S. Global Change Research Program that need real time observations from space were key factors in this study. The highest science priority of the overall Earth system, according to the Committee on Earth Science of the U.S. Global Change Research Program, was Climate and Hydrologic Systems with emphasis on the role of clouds.

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Scientific research discoveries are unpredictable and in recent decades the time between a scientific discovery and technological impact has been significantly reduced. The discoveries that led to the miniaturizing of electronics and subsequent phenomenal advances in computer hardware are examples of unplanned advances. To accommodate the unpredictability of scientific discoveries, the researcher must have flexibility. Unexpected findings usually require new measurements for confirmation, refinement, and application; consequently, the instruments or sensors comprising a measurement system require maximum flexibility. Adjustments to the measurement systems are routine in a traditional research laboratory. An unchangeable measurement system in space with a planned lifetime of years and a planned concept for a project duration of decades presents a hindrance to progress in science. Other more flexible measurement systems and new projects will take the place of the extinct project with fixed design measurement systems. The unpredictability of scientific discoveries requires flexible capabilities in the research and measurement systems.

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Focusing on the U.S. Global Change Research Program's highest priority science categories as a roadmap, this report shows how more than a dozen science topics or events evolved to become compatible with the EOS project. The rationale for their selection is discussed in the body of the report. Briefly, the selection criteria was based on whether the science was linked to an event (e.g., volcanic eruption) or highly time-dependent processes (e.g., convective storms). Through many examples the study shows how real-time data significantly benefits planned field experiments and how laboratory scientists can optimize their work using EOS data products received in real time. Further analyses led to the identification of time dependent science processes or events needing real-time data; these phenomena are categorized into the following basic groups: (1) stratospheric events and processes, (2) pollution events and transport, (3) tropospheric events and processes, (4) solar-terrestrial effects, and (5) ice systems.

... time- dependent science processes or events needing real-time data ...

- Stratospheric events and processes
- Pollution events and transport
- Tropospheric events and processes
- Solar-terrestrial effects
- Ice systems

The measurement capabilities of each of the more than 30 instruments being considered for the EOS project were evaluated using a matrix of criteria. An objective for instrument selection was to enhance the EOS mission through scientific achievements, and for programmatic recognition there was recognition of the potential for early results. Criteria for instrument selection included the following: (1) the concept of the real time direct-to-user requirement, (2) the potential for merged data products, (3) sensors of an instrument providing real time corrections to another instrument, (4) scientifically meaningful resolution, and (5) reasonable data rates. Nine instruments were selected as critical for real time science needs.

For each of five categories of scientific research, primary and secondary instruments were identified for real time scientific needs. The criteria were a mixture of direct applicability, potential for merged data products, capability to inject or supply correction data, and the data rate of the instrument. The most useful instruments for real time downlink for the five science categories are SAGE III/GLRS for stratospheric studies, TRACER/MODIS for pollution and transport, HIMSS/LIS/SCANSAT/MODIS/GLRS for tropospheric studies, XIE/IPIE for solar-terrestrial investigations, and HIMSS/GLRS for ice systems.[1] Several others are considered excellent contributing sensors.

EOS Instruments With Greatest Real-Time Potential

SAGE III/GLRS - stratospheric studies
TRACER/MODIS- pollution and transport
HIMSS/LIS/SCANSAT/MODIS/GLRS - tropospheric studies
XIE/IPIE - solar-terrestrial investigations
HIMSS/GLRS - ice systems

The prevailing concepts contain the inherent flaw that data on large-scale processes collected over long time periods are needed to understand the Earth system and improve climate prediction models. As noted in this study, rapidly changing microphysical and mesoscale processes are also important factors in understanding the Earth system and further demonstrate that for EOS to be successful, provision must be made for real time, direct to user flexible data processing and products, and direct support to other sensors. These flexible and merged data products require a reprogrammable onboard processing capability.

[1]See Table 2 in Section 2 for acronym definitions.

> ... for EOS to be successful, a provision must be made for real time, direct to user flexible data processing and products ... These flexible and merged data products require a reprogrammable onboard processing capability.

The important microphysical and mesoscale processes are best studied through field experiments (often remote and international) with direct-to-user data products. Also important are model developments using real-time data products. Unpredictable discoveries require flexibility in modeling methods and inversion techniques, and in having the capability to change onboard merged data-product algorithms. In addition, worldwide operational environmental forecast centers benefit from real-time data products and the operational users provide "feedback" to the researcher and project management.

The technical results of this study led to the following conclusions: EOS should provide a flexible design concept that supports research that can take advantage of real time downlink data from adaptable algorithms and models using data from one or more sensors. Using presently available data from instruments now in orbit (many of which have channels similar to those proposed for EOS), EOS can support the design of this onboard flexibility to allow accommodation of any unexpected discoveries in the next few years. It is the unpredictability of discoveries in science that requires flexibility in measurements and the need for the onboard processing capability to accommodate unforeseen EOS data applications. Before the first EOS vehicle is launched into space late in this decade, even greater advances in computer hardware and data processing software will have been made, which will make much of the complex instrument data processing very manageable for an onboard processing mode. A project with long-term (decades) impact must seriously consider the potential of onboard processing to provide the vital support required to maximize advances in science in the next quarter century, and take steps to achieve a real time, onboard processing capability on each EOS platform. The most important recommendation is that a real time adaptable downlink system, such as the Information Science Experiment System (ISES), be provided for each EOS platform.

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## 1. INTRODUCTION

The National Aeronautics and Space Administration (NASA) Earth Observing System (EOS) Program will provide quantitative measurements of the Earth's geophysical, chemical, and biological processes that govern environmental systems. Through synergistic, flexible measurement devices on low orbiting satellites, the EOS program will provide the international research community with global information on the Earth's atmosphere, oceans, and terrestrial processes. These new data sources are necessary for the advancement of the understanding of long term (decades to centuries) natural changes in climate and shorter (years to decades) changes in the Earth's environmental conditions that may now be in process. The EOS program data will provide the critical information for the international scientific community to analyze and acquire the fundamental understanding of the apparent ongoing changes in the Earth's environment and thereby identify the causes of change—natural or anthropogenic.

The EOS program complements and will supply measurements to many efforts, including the World Climate Research Program (WCRP), the International Geosphere-Biosphere Program (IGBP), and the U.S. Global Change Research Program (GCRP). The international scientific community, through organizations such as the International Council of Scientific Unions (ICSU), is planning many field experiments of the type which EOS could support directly, in real time. Planned international multidisciplinary experiments include the Coupled Ocean-Atmosphere Response Experiment (COARE), European Cirrus Research Experiment (EUREX), and Atlantic Climate Change Program (ACCP).

Instrument development activities are also international, such as the joint French and Soviet Union Scanners for Radiative Budget instruments scheduled for METEOR satellites or the joint United States and United Kingdom Atmospheric Infrared Sounder and Atmospheric Microwave Sounder Units to be incorporated into EOS. In preparation for the first EOS satellite launch, opportunities will exist for the exploitation of knowledge gained from the planned Global Energy and Water Cycle Experiment (GEWEX) continental U.S. ground truth network for space measurements of variables related to the hydrologic cycle. There will be opportunities to use the GEWEX ground truth network for calibration and for real time adjustments when EOS platforms are in orbit. The importance of space-derived data has been recognized by those planning experiments to study global change. Table 1 lists a few planned international field experiments that will use satellite data and other recent campaigns where research scientists in the field have used satellite data.

| TABLE 1. EXAMPLES OF PLANNED AND RECENT RESEARCH CAMPAIGNS RELYING ON SATELLITE DATA |
| --- |
| World Ocean Circulation Experiment (WOCE) |
| Global Energy and Water Cycle Experiment (GEWEX) |
| Marginal Ice Zone Experiment (MIZEX) |
| Airborne Arctic Stratospheric Expedition (AASE) |
| Experiment on Rapidly Intensifying Cyclones over the Atlantic (ERICA) |
| Arctic Cyclone Experiment (ACE) |

The role of real time satellite data in enhancing the success of field experiments has been shown many times. During the 1988 Marginal Ice Zone Experiment (MIZEX), scientists used real time satellite data to direct the on-ice efforts. In the 1989 Airborne Arctic Stratospheric Expedition (AASE), scientists studying polar ozone exploited near real time satellite data on polar stratospheric clouds to optimize aircraft scientific data acquisition flights. An integral part in the planning of many contemporary science campaigns is real time satellite data support, as was the case for the recently (1990) completed campaign of the Experiment on Rapidly Intensifying Cyclones over the Atlantic (ERICA). Sometimes a research campaign is saved by timely information derived from satellites, such was the case in the 1984 Arctic Cyclone Experiment (ACE) when a research aircraft was diverted in flight from the planned storm penetration to a newly developing storm as detected by satellite. This flight was the last one scheduled for the then unproductive campaign. The storm encountered was in its initial development, and for the first time scientists gained data on the genesis of these life threatening, rapidly developing (3- to 6-hr), destructive storms (hurricane force winds), which Emanuel and Rotuno (1989) have called "Arctic hurricanes." The Shapiro et al. (1987) report on the 1984 storm opened a new era in the understanding and prediction of these storms. In subsequent years, real time satellite data became paramount in the research and development on the prediction techniques for Arctic hurricanes.

Real time satellite data has also been shown to be a critical element in the study of other geophysical events; for example, when a University of

Washington research aircraft was diverted from the mission of the day to investigate the dust and gas plume from the volcano Redoubt. A wide variety of rapidly changing Earth's processes and events have occurred in which real time satellite data are often vital to improving understanding of these phenomena and enhancing the development of prediction techniques. Figure 1 summarizes and illustrates some of these phenomena where real time EOS sensor data would greatly benefit understanding.

The examples cited in the previous paragraph indicate the significant value of real time satellite data in the support of field experiments. In addition, investigators in the laboratory developing numerical models or other techniques for the prediction of both temporally and spatially variant events are also potential users of EOS measurements provided in real time. In the following section the needs of the research community for real time EOS measurements will be discussed further.

## 2. RESEARCH COMMUNITY NEEDS FOR REAL-TIME DATA

For this decade and into the next century, the international environmental research community will be addressing fundamental questions on the Earth's processes (natural and anthropogenic) that are believed to impact global climate change. These processes range from microphysical cloud generation mechanisms to global scale atmosphere and ocean circulation. These time and space variant processes, such as developing mesoscale convective complex cloud systems, ocean storms, and hurricanes, often occur where conventional observations are sparse, or the time intervals between observations are longer than the critical time for detection of the event. Such circumstances have slowed progress in understanding these and other time variant phenomena, particularly in regard to longer temporal changes in the Earth's environmental systems (such as the impact of changes in cloudiness on radiation balance or ocean warming on hurricane frequency). From the experience gained on previous field campaigns it is manifestly evident that increasing real-time information flow, with some critical onboard processing, would be of great value for field scientists studying a rapidly (minutes) changing event.

The occurrence of events such as volcanic eruptions, major forest fires, or widespread agricultural burning are also believed to have significant impact

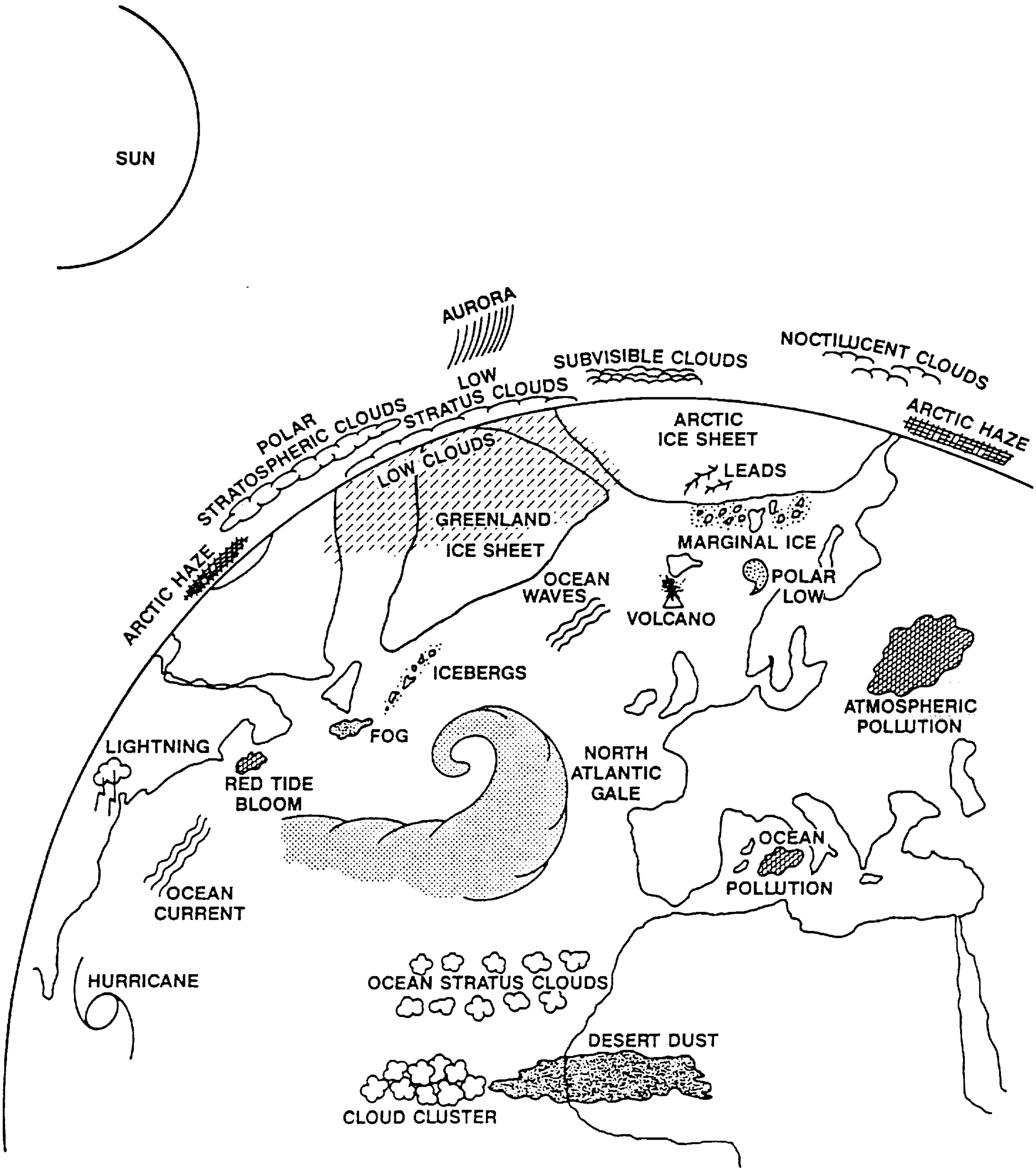


Figure 1. Geophysical, chemical, and biological processes and events requiring real time EOS processing to optimize research results.

on regional acid rain problems and on the radiation balance for very large (hemispherical) scales. Included under the category of events are plumes of material in the atmosphere (natural desert dust or industrial effluents) and patches of surface material on the ocean (natural biota bloom or an oil slick).

With the advent of EOS (Appendix A contains EOS sensor specifications), the research and applied technology communities will have the multispectral data acquired from the same platform in space measuring the same atmospheric column or surface area (land/oceans/ice). The theoreticians will have the opportunity to develop hypotheses using blended or fused information to unlock the mysteries of some processes, such as the multidimensional forces that steer a hurricane. Similarly, the laboratory investigator can develop techniques that assimilate information from a variety of EOS sensors on ocean (biota and physical characteristics) and atmospheric conditions to predict the onset of relatively local toxic dinoflagellate (red tide) and subsequent transport of the bloom. The capability to provide simultaneously acquired information is a strength of EOS and will be discussed throughout this report.

EOS will bring new capability to the international environmental science and technology community to advance understanding and prediction of geophysical, chemical, and biological events of Earth processes. These processes represent a broad range of events, from global solar-terrestrial processes through various scales of ocean and atmospheric systems, to cloud clusters of only a few kilometers in size.

EOS, as planned in 1990, will provide the international science community unique data to gain an understanding of Earth processes that may be changing global climate conditions. The EOS plan is to have mutually supporting sensors on the same space platform. In the following sections and in Appendix A of this report analyses and discussions are presented to show how the EOS sensors complement each other and a brief description of each instrument is given. With supporting instruments on the same platform a capability will exist to interchange correction factors between sensors. Also, EOS offers the unique potential to integrate simultaneously acquired information. These EOS features will enhance the researcher's ability to gain new insight into Earth events and processes.

Considering the EOS plan for instruments and priorities of the U.S. Global Change Research Program that EOS supports, the scientific literature was reviewed. In addition, personal contacts with leaders in the international scientific community were made to compile a list of examples of episodic and time-dependent phenomena that will benefit from EOS and the real time reporting of vital global change measurements. The examples reflect consideration of the U.S. Global Change Program science priorities as shown in Figure 2 and the potential of EOS to provide complete spectral coverage, as well as the need for the data in near real time for support to the international basic research and technique development communities.

The commonality for the selected phenomena listed in Table 2 has the potential to advance the understanding of the phenomena that are linked to global climate change. Advances in the understanding of the Earth's geophysical, chemical, and biological processes have traditionally resulted from measurements of important parameters in the field. Today the success of field experiments is significantly enhanced by using satellite data in concert with mobile observing platforms, such as ships and aircraft.

## 2.1 Mobile Platform Users of EOS Data

EOS real-time data users are many and will bring early recognition to the program with announcements of preliminary findings. (Examples of field campaign scientists using real time satellite data were given in Section 1.) A major pay-off category for EOS real-time data use are the field experiments involving airborne, platforms (helicopters, aircraft, and lighter than air vehicles), large ocean research vessels, and smaller coastal and inland waters research vessels. Operational costs for mobile platforms are high and increasing: a typical airborne platform will cost the research sponsor three thousand dollars an hour, and a major ship's costs are in the tens of thousands of dollars per day.

Airborne platforms are used by many in the pursuit of new knowledge from global stratospheric and tropospheric transport of material to localized industrial toxic plumes or natural cloud microphysical processes. Major field campaigns to study polar stratospheric ozone depletion and polar stratospheric clouds have employed aircraft and near real time satellite data. These projects

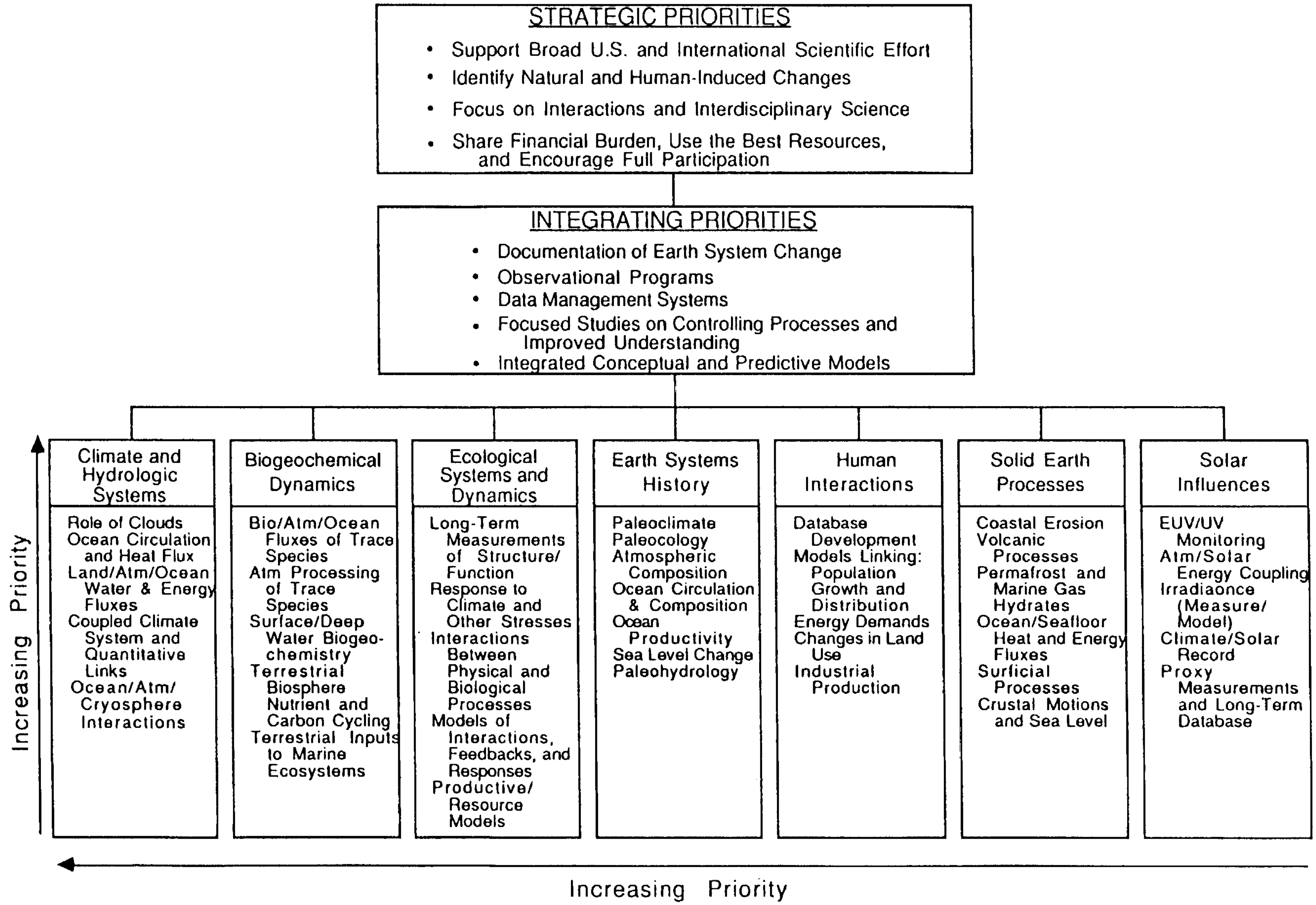


Figure 2. U.S. Global Change Research Program framework, from Our Changing Planet: The FY 1991 U.S. Global Change Research Program, a report by the Committee on Earth Sciences to accompany the U.S. President's fiscal year 1991 budget.

TABLE 2. EPISODIC AND TIME-DEPENDENT PHENOMENA SUPPORTED BY EOS DATA

| DESCRIPTION | RATIONALE |
|---|---|
| Solar-Terrestrial Reactions | - radiation/particle impingement/ionosphere |
| Mesospheric and Stratospheric Clouds | - radiation balance, linking of neutral atmosphere to ionosphere and to terrestrial gases and photochemistry of ozone hole |
| Polar Ozone Hole | - photochemistry/circulation of the stratosphere |
| Stratospheric Warming | - general circulation of atmosphere |
| Subvisible Cirrus | - radiation balance, attenuation and scattering |
| Volcanic Activity | - gas and particulate plumes, radiation balance |
| Transport of Desert Dust, Agricultural and Forest Fire Smoke | - radiation balance, acid deposition |
| Arctic Haze | - aerosols from leads/pollution |
| Pollution - Ocean and Troposphere | - industrial effluents |
| Ocean Productivity | - phytoplankton blooms |
| Mesoscale Convective Complexes | - severe weather prediction |
| Floods | - hydrologic cycle, soil conditions, prediction |
| Hurricanes/Typhoons | - prediction |
| Icebergs, Ice Sheet Dynamics | - shipping, climate impact |

include the 1986 National Ozone Experiment (NOZE), the Airborne Antarctic Ozone Experiment (AAOE) in 1987, and the Airborne Arctic Stratospheric Expedition (AASE) in 1989. Turco and Condon (1990) reported that 133.9 research hours were flown in 1989 during AASE. The aircraft missions in the remote Arctic regions were planned, in part, using, in almost real-time, data from the Stratospheric Aerosol and Gas Experiment II satellite. For some investigations, a blimp is a practical airborne platform; for example, Woods Hole Oceanographic Institution scientists will fly a scatterometer on a blimp to study variations in the ocean surface signal. Also, a group of Naval Research Laboratory scientists are planning, for the 1991 to 1994 period, a Transformation Dynamics of Marine Aerosols (TDMA) Program, which will need real time satellite data support. In this unique effort a ship and a blimp will drift with a terrestrial plume (natural material or industrial source) from a coastal region to several hundred miles off the coast.

Aircraft and ships are commonly used by scientists studying hurricanes, and middle and high latitude storms. In recent years, ocean storm research has increased. In projects like Genesis of Atlantic Lows Experiment (GALE), the scientists fused data from ships, buoys, aircraft, and satellites. According to Dirks (1988), in the first year of the GALE project more than 225 hr of research aircraft flight time was logged. A related project to GALE was the Canadian Atlantic Storms Programs (CASP), which like GALE and ERICA used research aircraft combined with satellite data. Further north, where data over the ocean is very sparse, Midtbo and Lystad (1987) reported that the Norwegian Polar Low Project also exploited satellite data in their field studies. In addition, Rasmussen and Aakjear (1989) have reported how the Danish scientists are using satellite data in real time. In the United States, efforts by Fett (1989), and Langland and Miller (1989) exemplified how U.S. laboratories have used the real time mobile data from field campaigns to develop research level prediction models. Satellite data routinely used by the field investigators have included not only vertical profiles of temperature and cloud imaging from visible and infrared sensors, but also the wide variety of data derived from microwave sensors. The EOS sensors will be able to support these types of campaigns in the future with far superior data that will include characterizations of ocean conditions, atmospheric structure, and cloud microphysics.

For many decades atmospheric scientists have been studying cloud microphysics from the ground, balloons, radar, and aircraft. During the period 1974-1984, Jeck (1986) reported 2,144 flight days of research aircraft obtaining cloud microphysical data. Apparently, a few of the 55 projects reported by Jeck used the aircraft data with real time satellite information. The high number of hours flown for these microphysical cloud experiments might have been reduced if real time satellite data were available. Data obtained in real time from EOS sensors fused with GOES NEXT (I,M) (as described by Shenk et al., 1985, 1986), from ground-based systems such as NEXRAD (reported by Leone et al., 1989), and the new wind profilers (reported by Post and Neff, 1986), will provide a new capability on cloud microphysics. Research scientists need to answer fundamental questions on rapid cloud structure changes. Some of these fast changes in mesoscale convective cloud complexes impact the larger scale processes, such as heavy precipitation or widespread cirrus clouds, which impact the Earth's radiation balance.

In recent years the use of multispectral satellite imagery by research scientists operating from research ships on the open ocean, and in coastal and inland waters, has increased. The marine biologists now use satellite-derived information to study phytoplankton and locate favorable conditions for pelagic fish. Chemical oceanographers use many of the same multispectral sensors in their investigations. Physical oceanographers can estimate the location of ocean fronts and eddies, estimate currents and tidal motions using operational sensors and special sensors particularly suitable for oceanographic research. Table 3 lists the sensors commonly used by contemporary ocean scientists, that are needed for real-time support.

EOS will overcome many of the problems that oceanographers have had and are continuing to experience in the use of satellite data. The generic problem has been the correction or conversion of the sensor data into meaningful oceanographic products. For example, variability of sea height and significant ocean wave height data have been obtained by the GEOSAT altimeter. GEOSAT is a satellite designed to map the geoid, but wind speed, wave height, and sea level variations can also be determined from the GEOSAT altimetric system. The satellite does not, however, have instruments to provide data to correct for

TABLE 3. SOME PAST AND PRESENT SATELLITE SENSORS USED BY OCEANOGRAPHERS

| SENSOR | ACRONYM | USE |
|---|---|---|
| Radar Altimeter | ALT | Ocean Topography |
| Advanced Very High Resolution Radiometer | AVHRR | Atmospheric Profiles and Sea Surface Temperatures |
| Coastal Zone Color Scanner | CZCS | For Ocean Color |
| Electronically Scanning Microwave Radiometer | ESMR | Rain Rate Mapping |
| High Resolution Infrared Sounder | HIRS | Atmospheric Profiles and Sea Surface Temperature |
| Infrared Interferometer | IRIS | Atmospheric Sounder |
| Multispectral Scanner | MSS | Land Applications |
| Microwave Sounder Unit | MSU | Atmospheric Profiles |
| Synthetic Aperture Radar | SAR | Ocean Surface and Ice Characterization |
| Scanning Multichannel Microwave Radiometer | SMMR | Ocean Surface and Ice Mapping |

atmospheric water vapor and electron content in the ionosphere; a situation rectified by EOS. The need for ocean topographic data, by oceanographers at sea and by wave prediction modelers, has motivated research scientists to overcome some of the signal path delay correction problems by sophisticated use of ground-based computer facilities. An example showing how EOS could greatly simplify the present complexities in computing that the oceanographers now experience will be discussed later in this report.

## 2.2 Research Campaign Users of EOS Data

Scientists investigating high altitude atmospheric phenomena and the ionosphere use rockets to obtain in situ data. Utah State University conducted a campaign in July/August 1986 called the Mesospheric Ionization Structure and Turbulence Investigation (MISTI). An objective of the campaign was to launch a rocket from Poker Flat Rocket Range in Alaska into mesospheric (noctilucent) clouds. The instrumented rocket launching was planned when both the ultraviolet spectrometer on the satellite Solar Mesospheric Explorer (SME) was detecting polar mesospheric (noctilucent) clouds over Poker Flat, and the mesospheric-stratospheric-tropospheric (MST) radar at the launch site was indicating turbulence. Timing the rocket launch with the SME orbit, meaningful radar echoes, air traffic control clearing of regional air space, and launch weather conditions were reported by Ulwick (1988) to be difficult, but the campaign was successful in obtaining simultaneously ground-based radar, in situ rocket data and satellite measurements of polar mesospheric clouds. Later in 1986, the radar was moved and the SME satellite was turned off. A need exists for more MISTI-like campaigns as questions are being asked on the effect of mesospheric (noctilucent) clouds on re-entry of the Shuttle, and other effects on the Earth's radiation balance.

Controversy has arisen within the scientific community on the definition of polar mesospheric clouds and noctilucent clouds. The latter are sighted in a narrow latitudinal band from about 55° to 65° and believed to be cloud particles 100 $\mu m$ or greater in size. The polar mesospheric clouds are measured from about 50° to 90° and believed to be 50 $\mu m$ or smaller in size. Each category is believed to have different nucleation processes. The EOS project could help resolve these issues. The size, distribution, and formation processes are important parameters for understanding the Earth system's radiation balance.

Recently Thomas et al. (1989) have published evidence that the increase in noctilucent cloud sightings in recent decades may be linked to increases in methane in the mesosphere. The transport of methane into the mesosphere is not understood; however, Juckes and McIntyre (1987) have numerically simulated high atmosphere breaking waves, a mechanism for vertical transport in the atmosphere. Orchestrating real time EOS data with rocket campaigns, such as MISTI, could test the increasing mesospheric methane hypothesis and provide data for stratospheric/mesospheric models with data at the spatial and temporal scales needed to verify the breaking wave hypothesis.

## 2.3 International Users of EOS Data

EOS will provide global data on geophysical, chemical, and biological processes of direct and real time interest to foreign scientists concerned with the environment. At the Geophysical Institute in Copenhagen, Denmark, mesoscale storm prediction models are being developed using data derived in real time from field experiments. EOS has several sensors that could provide data to the mesoscale prediction modelers in real time at facilities such as the Meteorological Office in Bracknell, England, where an effort is underway to develop numerical nowcasting models fusing radar and satellite data. Laboratory scientists in France and the Netherlands are developing methods for the retrieval of mesoscale meteorological parameters from satellite sensors and applying the algorithms with real-time data during field campaigns. Also, in France, Sand (1990) and his colleagues are developing algorithms using the Defense Meteorological Satellite Program (DSMP) and Special Sensor Microwave Imager (SSM/I), combined with field experiment data (aircraft, radiosonde, radar and surface measurements) and other satellite data. A reasonable assumption is that the European investigators, using the Coastal Zone Color Scanner data to study open ocean coccolithophroid blooms, will be strong candidates for real time use of EOS Moderate Resolution Imaging Spectrometer (MODIS) and High Resolution Imaging Spectrometer (HIRIS) data. Coccolithophroids produce dimethylsulfide (DMS), which converts to sulfonic acid (MSA) and sulfuric acid. Then, according to Hoppel (1987), MSA plays an important role in creating particulates for the cloud condensation nuclei of maritime clouds. Twomey et al. (1987) have linked pollution to reflectance (albedo) of maritime clouds. Coakley and his associates (1988) have suggested that maritime clouds provide a key impact on global temperature changes. The "biota-to-gas-to-aerosols-to-cloud" hypothesis has motivated field measurement efforts, such as the 1989 campaign using the NOAA ship *RV MacArthur* and the University of Washington research aircraft off the U.S. northwest coast.

## 2.4 Development Laboratories Real Time Use of EOS Data

In the United States and throughout the world some laboratories have a charter to develop diagnostic and prediction models of geophysical, chemical, or biological processes that impact the environment and the well-being of people. Real time satellite data are routinely incorporated into prediction methods for environmental conditions. In order to develop these methods, the laboratory staffs use real time satellite data. The methods range from the analysis of marine aerosols to regional sea surface characteristics and prediction techniques of mountain winds in Switzerland to large typhoons over the Pacific Ocean.

The technique developers listed in Table 4 represent some of the facilities continually trying new ways to use real time satellite information, particularly data from new sensors. The Defense Meteorological Satellite Program (DMSP), for example, launched a satellite in June 1987 carrying a new instrument, the SSM/I. Data from the instrument (even during initial operational testing) was made available to the international technology community. The extraordinary early application of this instrument is a credit to the military (Air Force and Navy) sponsors who planned and developed the retrieval algorithms well before launch. At the 1988 Hurricane and Tropical Meteorology Conference in San Diego, California (just 6 months after launch), 10 or more papers were presented on SSM/I applications to hurricane and typhoon position fixing, rainfall amounts, and track prediction. At the Fifth International Conference on Satellite Meteorology and Oceanography, which is scheduled for September 1990 at the Royal Society in London, England, entire sessions will be dedicated to SSM/I applications. Many of the papers for these sessions have been submitted from laboratories, institutes, and operational meteorological services.

TABLE 4. PARTIAL LIST OF LABORATORIES ROUTINELY USING NEAR REAL TIME SATELLITE DATA

| | |
|---|---|
| Royal Netherlands Meteorological Institute | Netherlands |
| Laboratory de Meteorologic Dynamique | France |
| Centre de Recherches en Physique de L'environment Terrestre et Planetaire | France |
| Meteorological Office | England |
| Norwegian Meteorological Institute | Norway |
| Nansen Remote Sensing Center | Norway |
| Swedish Meteorological and Hydrological Institute | Sweden |
| Swiss Meteorological Institute | Switzerland |
| Forecast Systems Laboratories (NOAA) | U.S. |
| Geophysics Laboratory (Air Force) | U.S. |
| Naval Oceanographic and Atmospheric Laboratories (USN) | U.S. |
| Atmospheric Sciences Laboratory (Army) | U.S. |

The success of SSM/I near real time operational and research use is due in part to the ability to "test" algorithms using similar sensor channels on NASA experimental instruments, such as the Scanning Multichannel Microwave Radiometer (SMMR). Gloersen, and his associates at NASA (1989), developed (with Navy funding) a technique for estimating polar lows with SMMR. The concept is transportable to SSM/I. The decision to send immediately (days after launch) real time SSM/I data (yet to be verified) to operational centers, such as the Joint Typhoon Warning Center in Guam, was important. In a few months, SSM/I became well known to the international scientific, technological, operational, and funding organizations in the United States and abroad. EOS could well learn from the success of the SSM/I near real time data programs.

## 2.5 Data Merging

Data merging or fusion can be considered at the project level, platform level, and product preparation level. At the project level, an example may be the experiments conducted in support of the Konza Prairie Long Term Ecological Research (LTER) Project in Kansas. Under the World Meteorological Organization (WMO), the International Commission of Scientific Unions (ICSU) established the International Satellite Land Surface Climatology Project (ISLSCP). The First ISLSCP Field Experiment (FIFE) was planned to use data from the NOAA, SPOT, LANDSAT, and GOES platforms. The remotely sensed data from the satellites were used with ground based remote sensors, such as sound direction and ranging (SODAR) and light detection and ranging (LIDAR) sensors. The remotely sensed data were used with aircraft data and more conventional in situ measurements.

For the FIFE scientists the site was fixed. Figure 3 illustrates the complexity of the observation system designed to simultaneously acquire satellite, airborne, and ground-based data for analyses and development of data sets and hypotheses for EOS. While FIFE was at a fixed site, scientists studying such phenomena as ionospheric variability, cloud clusters, hurricanes, flooding, biota on the ocean, or other events (such as a volcanic eruption) have the added complexity of needing real-time data to direct resources or possibly change the operational mode of a spacecraft instrument.

Figure 4 illustrates the wide variety of research data collection resources required for field experiments. Real-time data is crucial for many experiments and can optimize the use of these resources, greatly enhancing the success of the experiment. Also, real-time data provided to laboratories developing new techniques will accelerate the transition of an experimental sensor to an operational instrument or system. Figure 4 builds on Figure 1 in a generic way illustrating how EOS could be a vital supplier of real-time data.

# 3. ANALYSIS OF EOS FOR REAL-TIME RESEARCH SUPPORT

In the previous section, research of science topics related to episodic and time-dependent phenomena were identified on the basis of the U.S. Global Change Research Program, literature review, and discussions with leading international scientists, as well as many of the EOS principal investigators.

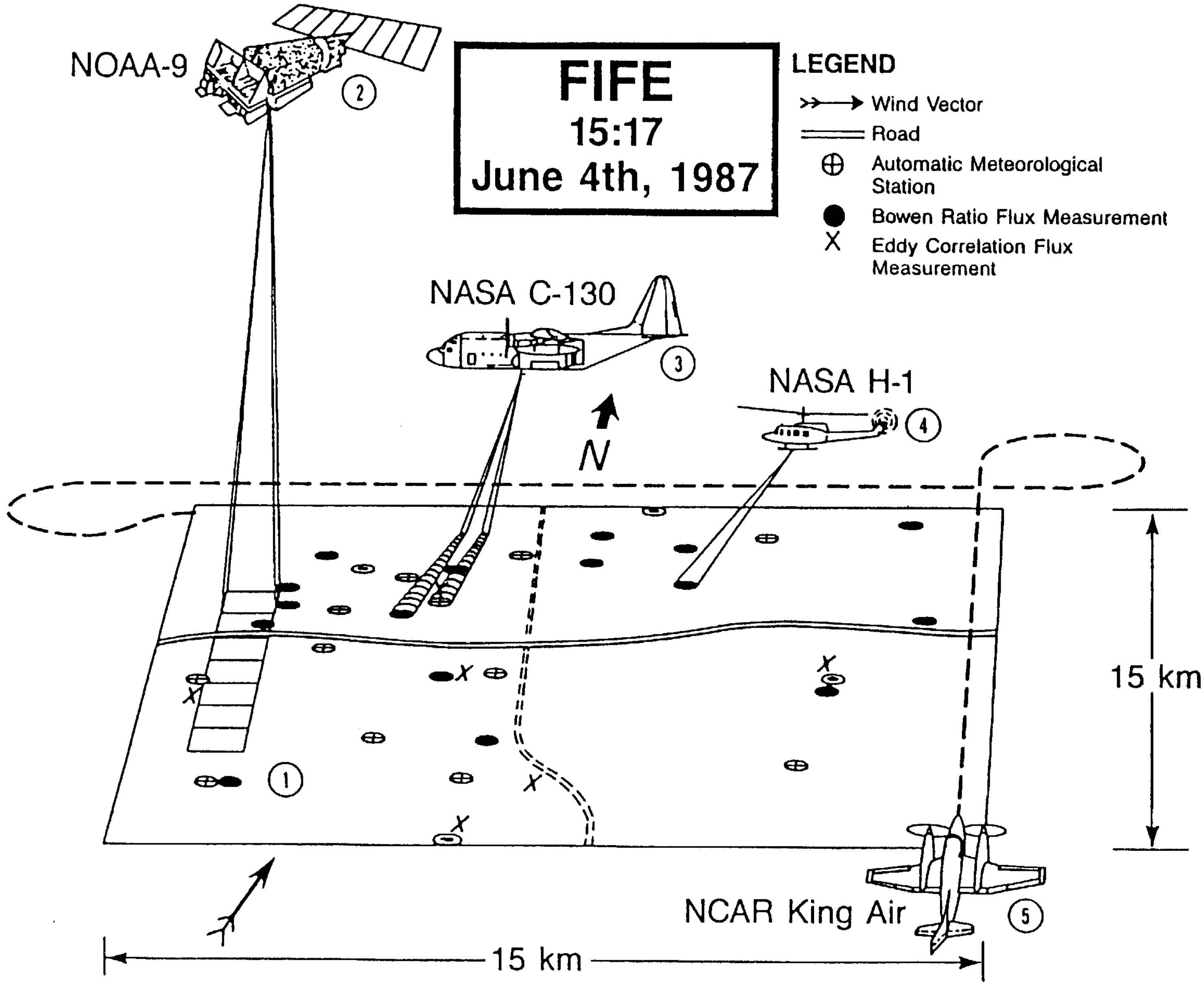


Figure 3. **Situation at the FIFE Site at 1517, 4 June 1987: An example of satellite data supporting a research campaign (Sellers et al., 1988).**

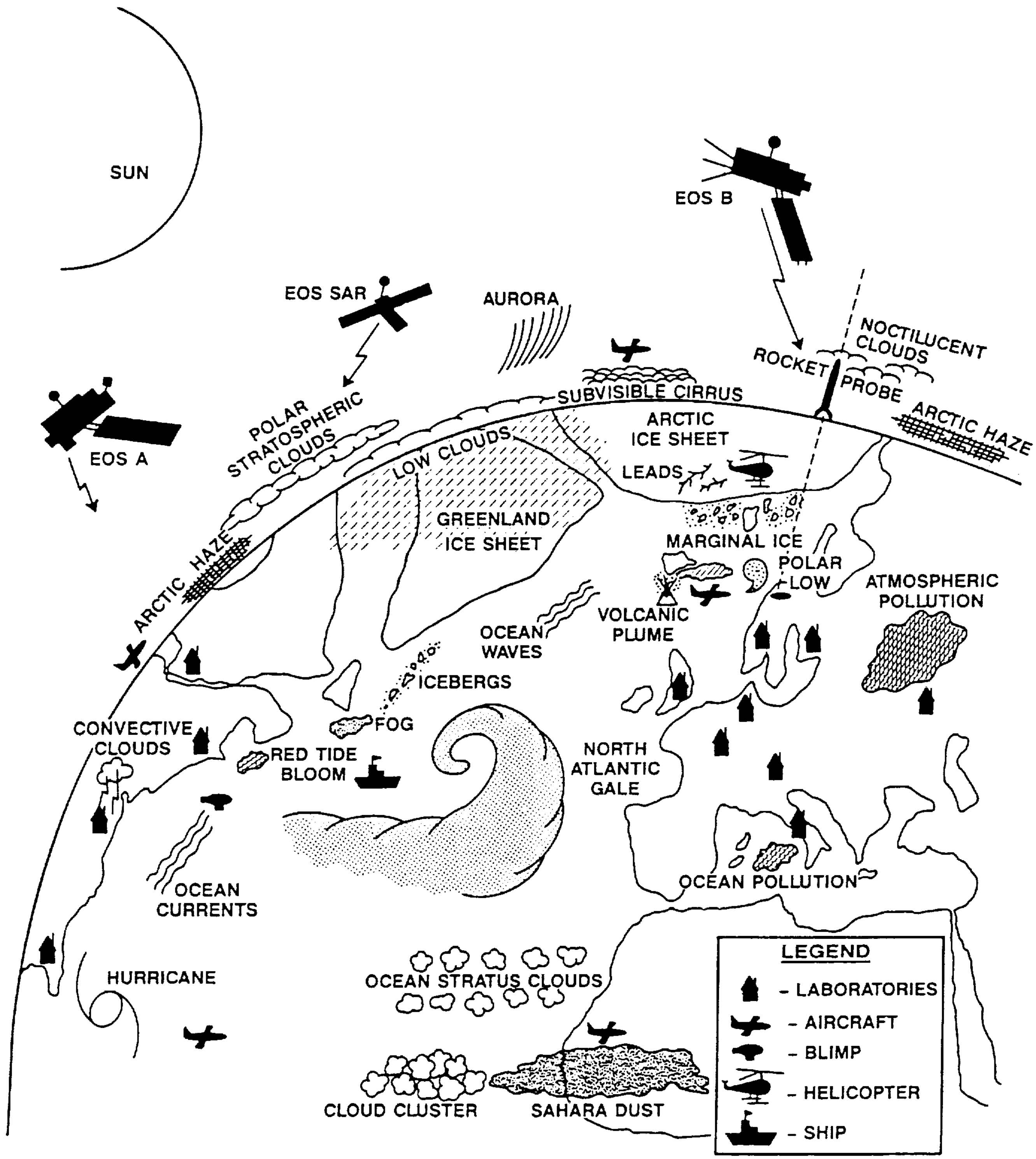


Figure 4. Research data collection systems (shown in solid black) requiring real-time EOS data to optimize study of geophysical, chemical, and biological events or processes depicted.

Readers of this report will likely be familiar with the EOS instruments; however, for completeness the instruments are listed by acronym and name in Table 5 as they appear in the EOS 1990 Reference Handbook. The typical phenomena to be observed by the instruments are listed in Table 6. Additional descriptions of the EOS sensors (full specifications, to include spectral/spatial coverage, data/data rate requirements, etc.) are found in Appendix A.

The geophysical, chemical, and biological phenomena related to these events were further analyzed, relating their merits with the contribution from the EOS sensors, which should be able to measure the needed data in real time. The wide spectrum of topics or events ranging from solar variability to cloud microphysics necessitated a topic-by-topic analysis. (The rationale and procedure followed to compile the list of science topics/events shown in Table 2 have been described earlier.) A brief description of each topic/event will follow.

Solar-terrestrial relationships have been studied for many decades, and much is now understood concerning the ways polar flares, for example, influence the Earth's geomagnetic field, perturb the ionosphere, produce aurora, and cause communication difficulties. What has escaped explanation is how solar variability is linked to weather and climate. The role of solar variability in the production of clouds has been discussed for many decades. Hypotheses include the formation of clouds from solar corpuscular impingement on the Earth's atmosphere, changing the electrical properties of charged particles that facilitate the formation of cloud condensation nuclei.

Another hypothesis is that increased ultraviolet radiation reaching the Earth's surface (natural bursts from the Sun) or ozone depletions (caused by man) produce changes in biological processes at the Earth's surface. Warren et al. (1985) noted that the Earth's surface is approximately three-fourths ocean and mostly cloud covered. Over the oceans are gas-to-particle conversion processes that may lead to increased marine cloudiness. The most common process discussed in contemporary literature (e.g., Charlson et al., 1987) is the relationship of dimethylsulfide (DMS) production at sea to increased water droplets in clouds. The more marine clouds, the more reflectance of the Sun's energy back to space. A change in cloud albedo, say from 0.2 to 0.3, reflects to space an additional 140 MW per square kilometer, at high Sun elevation. Note that the thin to

TABLE 5. EOS Instruments

| ACRONYM | TITLE |
|---|---|
| | Facility Instruments |
| AIRS | Atmospheric Infrared Sounder |
| AMSU-A | Advanced Microwave Sounding Unit-A |
| AMSU-B | Advanced Microwave Sounding Unit-B |
| ALT | Altimeter |
| GLRS | Geoscience Laser Ranging System |
| HIRIS | High-Resolution Imaging Spectrometer |
| LAWS | Laser Atmospheric Wind Sounder |
| MODIS-N/T | Moderate-Resolution Imaging Spectrometer-Nadir/Tilt |
| EOS SAR | EOS Synthetic Aperture Radar |
| | Other Instruments |
| ACRIM | Active Cavity Radiometer Irradiance Monitor |
| CERES | Clouds and the Earth's Radiant Energy System |
| ENACEOS | Energetic Neutral Atom Camera for EOS |
| EOSP | Earth Observing Scanning Polarimeter |
| GGI | GPS (Global Positioning System) Geoscience Instrument |
| GOS | Geomagnetic Observing Station |
| HIMSS | High-Resolution Microwave Spectrometer Sounder |
| HIRDLS | High-Resolution Dynamics Link Sounder |
| IPEI | Ionospheric Plasma and Electrodynamics Instrument |
| LIS | Lightning Imaging Sensor |
| MISR | Multiangle Imaging Spectro-Radiometer |
| MLS | Microwave Limb Sounder |
| MOPITT | Measurements of Pollution in the Troposphere |
| POEMS | Position Electron Magnet Spectrometer |
| SAFIRE | Spectroscopy of the Atmosphere Using Far Infrared Emission |
| SAGE III | Stratospheric Aerosol and Gas Experiment III |
| SCANSAT | Advanced (duel pencil-beam) Scatterometer |
| STIKSCAT | Advanced (classical fan-beam) Scatterometer |
| SOLTICE | Solar Stellar Irradiance Comparison Experiment |
| SWIRLS | Stratospheric Wind Infrared Limb Sounder |
| TES | Tropospheric Emission Spectrometer |
| TRACER | Tropospheric Radiometer for Atmospheric Chemistry and Environmental Research |
| TRAMAR | Tropical Rain Mapping Radar |
| XIE | X-Ray Imaging Experiment |

Table 6. Brief Description of EOS Measurements

| Sensor | Phenomena to Be Observed |
|---|---|
| AIRS and AMSU | Temperature and water vapor profiles, surface and cloud processes, atmospheric chemistry |
| ALT | Ocean and polar ice topography, ocean currents, surface winds, and wave height |
| GLRS | Crustal motion (fault displacement) ice sheet topography and motion, cloud tops, and geological processes |
| HIRIS | Surface features (snow line, vegetation changes, wetland borders) and other biogeophysical measurements |
| LAWS | Winds, aerosols, and clouds |
| MODIS N/T | Biological and physical processes including ocean productivity (chlorophyll), soil/vegetation and snow/ice differences, clouds (height, fraction and temperature), aerosols, and particulates from forest fires and volcanoes. |
| EOS-SAR | Soil, snow, canopy moisture, flooded regions, sea ice, and ocean processes |
| ITIR | Rock classification, clouds, evapotransperation, vegetation, and volcanology |
| ACRIM | Variability of total solar irradiance |
| CERES | Radiation budget, cloud coverage and height, liquid water content |
| ENACEOS | Magnetosphere by measuring energetic neutral atoms (H, He, etc.) to several MEV; measures precipitating and trapped ions at satellite altitude |
| EOSP | Cloud properties (optical thickness, particle size, phase), aerosols |
| GGI | Geodesy, platform position, temperature profiling, ionospheric gravity waves, topography of ionosphere |

Table 6. Brief Description of EOS Measurements (continued)

| Sensor | Phenomena to be Observed |
|---|---|
| GOS | Magnetic field, mantle conductivity, ionospheric effects |
| HIMSS | Precipitation rate, cloud water, water vapor, temperature profiles, sea and snow surface |
| HiDRLS | Atmospheric temperature and constituents from upper troposphere to mesosphere |
| IPEI | Ionospheric constituents, ion concentration and drift |
| LIS | Intracloud and cloud-to-ground lightning |
| MISR | Aerosols, cloud and vegetation properties |
| MLS | Vertical profiles of atmospheric constituents |
| MOPITT | Carbon monoxide in the troposphere |
| POEMS | Positrons and electrons from 5 MEV to 5 GEV |
| SAFIRE | Atmospheric constituents, vertical profiles of temperature, solar events, volcanic eruptions |
| SAGE III | Profiles of aerosols, polar stratospheric clouds, profiles of atmospheric (greenhouse) gases |
| SCANSCAT/STIKSCAT | Ocean surface winds |
| SOLSTICE | Solar ultraviolet radiance |
| SWIRLS | Vertical profiles of atmospheric constituents, winds in the stratosphere |
| TES | Infrared emission from many atmospheric constituents from Earth's surface to stratosphere |
| TRACER | CO, volcanic plumes, pollution, and processes |
| TRAMAR | Rain rate in the tropics |
| XIE | X-ray, particulate energy |

moderate low-level clouds are the most sensitive to added nuclei. Without adequate knowledge on cloud feedback processes, particularly on low marine clouds, simulation of the atmosphere for the purpose of predicting global climatic temperature changes will continue to be difficult for numerical modelers.

Field experiments, such as the previously mentioned TDMA, are now being planned to study marine cloud formation. These operations are expensive, involving aircraft, blimps, and ships. Real time satellite data transmitted directly to the location of these large experiments would greatly enhance their success.

Near the tropopause and into the lower stratosphere (10- to 15-km altitude) cirrus clouds are found. These phenomena are difficult to factor into climate simulation models because historical data on their occurrence is incomplete, and their effect on the radiation balance is not fully understood (nighttime cirrus has been traditionally underreported). Satellite observations, such as reported by Woodbury and McCormick (1983), have improved understanding of global cirrus cloud distribution.

To complicate the cloud issue are the recent discoveries of subvisible cirrus, polar stratospheric clouds, and extensive coverage of polar summer skies with polar mesospheric clouds (PMCs). Satellite borne limb scanning instruments now in orbit have also measured the ubiquitous winter polar stratospheric clouds (PSCs). Extensive documentation confirms that PSCs cover most, if not all, of the darkened winter Southern Hemisphere polar stratosphere. Also, Rosen (1987) and his colleagues reported that PSCs are considered important in the ozone depletion process. These PSCs are not discernible from the ground but can be observed continuously for years by instruments such as SAM II and SAGE, and soon the U.S. Polar Ozone Aerosol Measurement (POAM) instrument scheduled to orbit on the French SPOT 3 satellite. These clouds can also be measured over a fixed spot for a limited period by ground-based lidars.

High in the atmosphere (85 km) is a circumpolar shroud of ice particles which forms every summer season, now known as polar mesospheric clouds. For the past century, however, they were known to ground observers as noctilucent clouds.

These observations were not common and were only noted between 55°N and about 65°N. The spatial extent and optical depth of the traditional noctilucent clouds were unknown until the recent satellite observations. Early estimates of the radiative impact of traditional noctilucent clouds on climate concluded that the layers may have an impact on regional climate, but not the global climate. These studies, however, did not have the advantage of recent information on opacity and particle size distributions for polar mesospheric clouds, which extend from 55°N to 90°N. These clouds have maximum opacity above polar regions in 24-hr solar illumination. A controversy exists as to whether the classic ground observed clouds are the same as the satellite measured clouds. The possibility that the polar mesospheric clouds and/or noctilucent clouds are increasing in time may be related to the well-documented increase in atmospheric methane, which is a major contributor to upper atmospheric water vapor and, hence, cloud opacity. These clouds may be a highly visible pointer to methane buildup and, in time, may themselves provide a radiative impact. Plans have been developed for campaigns to obtain (with a rocket) experimental information on the particle size and brightness of noctilucent clouds. An optical model for particle size and concentration is being developed based on data from NASA's long term ozone monitoring program; however, ultraviolet albedo data from satellites, such as the old Solar Mesospheric Explorer, are no longer available.

Material injected into the atmosphere from volcanoes or from anthropogenic sources such as agricultural burning (Newell et al., 1989), industrial products as carbon dioxide, nitrous oxide and particulates, or trace gases including methane, are all related to clouds. Many basic science questions concern clouds and the availability of water vapor; for example, is the building of methane-derived water vapor at 85 km due to events (volcanic injection of water), or to periodic effects of solar variability? EOS sensors can greatly assist serious efforts of the international scientific community to improve the understanding of such processes. An early result based on available real-time EOS data would enhance understanding and benefit all scientists concerned about global change.

Transport of desert dust, forest fire smoke, industrial pollutants, volcanic gases and particulates, and natural gases or particulates originating from decaying organics require continuous monitoring for scientific and societal reasons. The scientific questions include those concerning the impact on global radiation balance to limited areas, and short duration sources of cloud condensation nuclei contributing to localized precipitation. These sources could be a desert, producing a large plume of dust, or a point source volcanic eruption. The widespread transport of such dust clouds is important for applying corrections to space sensors measuring surface features such as sea surface temperature. Industrial sources of atmospheric material also could be transported long distances, resulting in phenomena such as Arctic haze, or mesospheric clouds possibly a result of methane, presumably produced at the Earth's surface and reaching altitudes of 85 km. Toxic plumes are usually short lived and localized, which means quick detection and rapid response for tracking is needed. Very rapid detection and tracking of a volcanic plume is critical for aviation. Modern aircraft engines fail in gas clouds or when volcanic dust is ingested. Several cases of simultaneous four engine failures have occurred in these invisible gas plumes. The EOS sensors will be capable of rapid detection, identification, and subsequent tracking of atmospheric gas plumes and dust. The rapid detection and identification of these plumes will be a major asset to EOS if the data can reach the user in a timely matter, possibly a few minutes. EOS is capable, with onboard processing, of providing in real time, critical information on the transport of natural aeolian material or pollutants.

Processes in the ocean surface top-half millimeter are extremely important in determining the skin temperature and evaporation. Natural phytoplankton blooms have been correlated with surface salinity and nutrients. The toxic blooms are of particular interest. Mulligan (1974) reported that the toxic dinoflagellates causing the "red tide" have been related to continental run off from floods, or the passage of a hurricane at sea. The surface reduction of salinity is believed to be a major prerequisite for these toxic blooms that can cripple a coastal shellfish industry, and if not detected, can cause serious illness and death to people eating the shellfish that had fed on the dinoflagellates.

The excessive rainfall from mesoscale convective cloud clusters over land can produce severe flooding and run off into coastal waters. Over the ocean convective cloud clusters can lead to storms and hurricanes that produce very heavy rains. Timely detection, analysis, and reporting of these events are added real time opportunities and needs for EOS support.

Clouds over ocean regions occur four times more frequently than over land. Since three-fourths of the global surface is water, the oceans are the largest providers of water vapor, which is the most important greenhouse gas in the atmosphere. Current climate models parameterize water vapor in terms of relative humidity; as a result, computed water vapor concentrations are linked simply to temperature (via, the Clausius-Clapeyron equation). Little attention is given to residence time, which could also change, and which is just as important as the injection rate at the ocean surface. For example, Scully-Power and Twitchell (1975) have shown that, under certain atmospheric conditions, a marine cloud will form by local transport of water vapor upwards, with surface temperatures only a few tenths of a degree warmer than the surrounding ocean. The variability of cloud occurrence at all levels of the atmosphere has been a traditional problem for climate modelers to parameterize. Recently Bengtsson and Shuklu (1988) reported on the unsatisfactory use of space derived cloud data in global climate change models. Early global climate models used fixed cloud input. The notorious unpredictability of precipitation is even more difficult to parameterize or properly measure. Understanding and relating these features often depends upon the simultaneous consideration and monitoring of numerous variables, many of which are only easily monitored in near real time.

Ocean surface temperature is critical in the development of hurricanes and plays a major role in the generation of destructive mid-latitude storms. Also, at high latitudes the sea surface temperature is believed to be important in the generation of polar lows. A polar low can develop in 3 to 6 hr producing heavy precipitation and gale- to hurricane-force winds. Contemporary operational meteorological satellites provide (from visible and infrared sensors) cloud top imagery and limited information on the vertical structure of the atmosphere. EOS will have far superior capability in cloud discrimination (height and composition), superior data on vertical structure of temperature and water vapor, and the capability of "seeing" the Earth's surface to determine soil moisture and ocean data. With these improved capabilities, EOS sensors will be capable of precisely locating and measuring the severity of weather systems from convective cloud clusters to major hurricanes. The microwave sensor capability will be particularly valuable for ocean storms. The EOS capability should not be wasted by delayed data availability to field research scientists and operational users. Data only a few hours old is useless to the hurricane forecaster attempting to predict landfall of a life-threatening ocean storm where heavy precipitation and flooding will occur along a river valley. EOS sensors can and should be orchestrated automatically by algorithms onboard the vehicle monitoring specific channels of selected instruments. These algorithms could automatically point another sensor or merge channels from various instruments to provide precise data on a severe weather phenomena, such as a rapidly (minutes to hours) developing convective cloud system capable of producing a flashflood or the genesis of a polar low in the Bering Sea that could threaten a fishing fleet.

The detection and location of icebergs in near real time will obviously benefit commercial shipping at high latitudes, and the characterization of ocean ice sheet dynamics has real time importance to the military but also to civilian weather forecast centers. Leads (open water) in the ice are now believed to be a heat source in the Arctic and modelers are attempting to parameterize the subsequent rapid and localized intense changes in boundary layer conditions. An ambitious field campaign to study leads is now in the planning stage. These scientists need data on the changes in the ice sheets in real time as they try to improve their models particularly in regard to cloudiness.

For most if not all of the science topics or events, the ability to "look ahead" with a sensor is advantageous. When a threshold in a particular channel is reached it can trigger the pointing of another sensor; or it can initiate algorithms to process level 0 signals from several sensors to produce an indicator or possibly a level 2 value of some environmental variable for immediate transmission to a user. EOS instruments have this potential.

The scientific topics/events requiring real time satellite data (listed in Table 2) resulted from a critical analysis of scientific questions presently impeding progress in understanding global change. Clouds at all levels of the atmosphere are clearly important in driving the radiation budget, hydrological cycle, and carbon cycle, and must be better understood for assimilation into climate prediction models.

The scientific importance of the selected topics and the need for EOS instruments to provide time-dependent data has been shown in the previously discussed examples of field experiments. The laboratory experimentalist also needs real time, direct to user time-dependent data from EOS sensors. For example, scientists investigating mesoscale processes, such as mesoscale cloud complexes or ocean eddies, have found the smaller scale processes are of key importance in understanding Earth systems. For that reason most major environmental prediction facilities are developing and testing local area models using highly time dependent perishable data, including satellite data. These local area models are being developed by meteorologists to improve predictions of severe weather on short time scales and to "mesh" these local area models into global models to improve larger scale predictions of the atmosphere.

In England, the research and development for prediction models is pursued at the same facility where the models are ultimately used by the operational weather service. That facility is at Bracknell near London. Figure 5 illustrates their national and international links to data sources and users. Similar conceptual diagrams can be shown for any meteorological or oceanographic forecast center. Bracknell scientists have produced operational systems such as Forecasting Rain Optimized using New Techniques of Interactively Enhanced Radar and Satellite (FRONTIERS), which was developed using real-time radar and satellite data interactively. This operational real time system processes highly perishable information that is delivered to the customer with absolute minimal delay.

Today a new system, call Autosat-2, is being developed at Bracknell using real time satellite data that will provide meteorological products for their customers in the 1990s. One of the principal assumptions behind the design of Autosat-2 is that the effective exploitation of meteorological satellite data requires that they be combined with other appropriate data, including conventional and model-based analyses as well as observations and geographical information. This asssumption implies the timely reprojection of images to a set of common chart areas. In order to minimize the time needed to produce a product, all relevant information pertaining to a pixel that changes in space or time is precomputed in lookup tables. Autosat-2 will initially use data from several sources, including NOAA polar-orbiting satellites, METEOSAT, and other

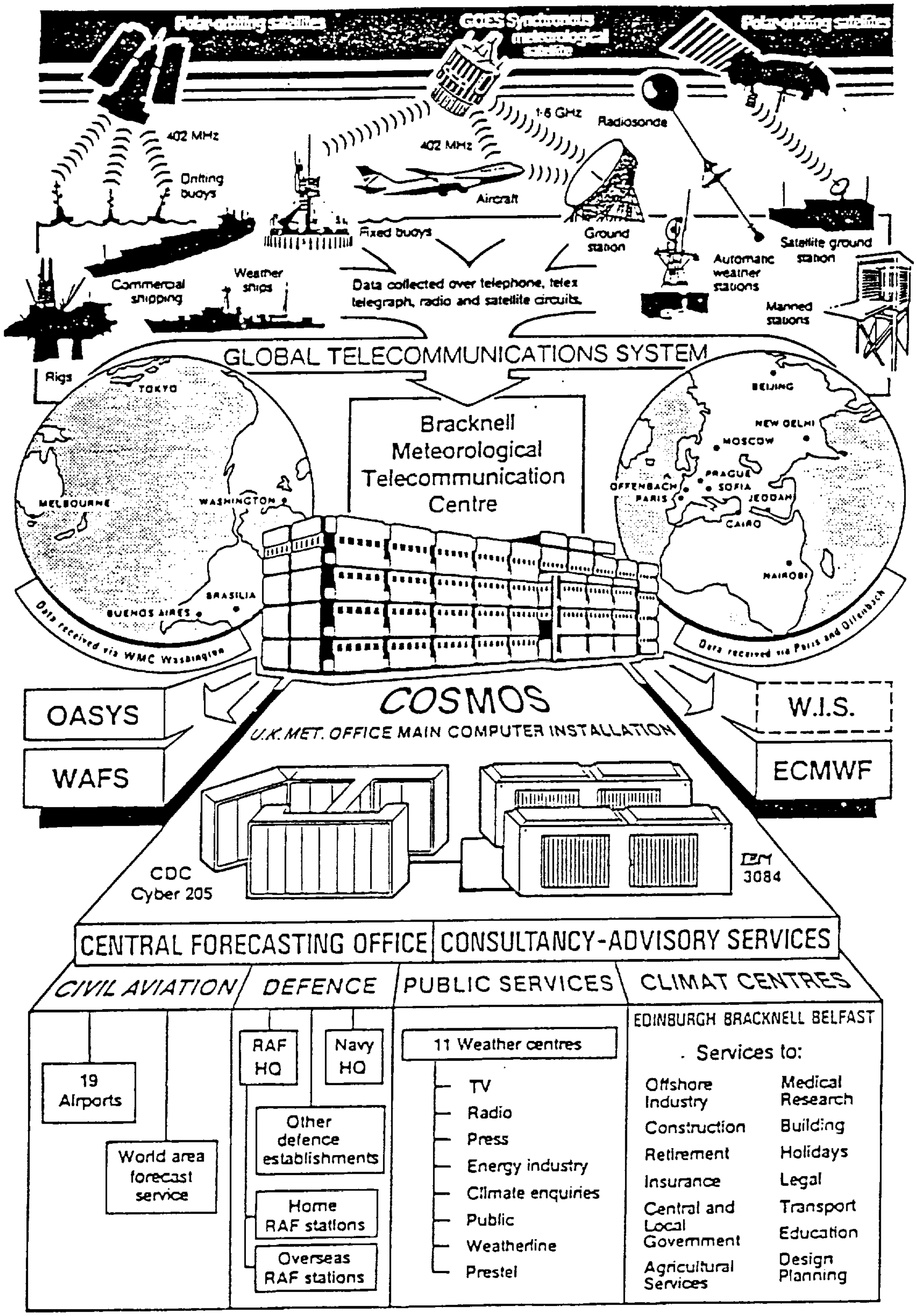


Figure 5. Global observing and collecting system, United Kingdom automated processing system for research, model development, forecasting, and consultancy services (courtesy of Richard Allam, U.K. Meteorological Office).

polar orbiting and geostationary satellites. The extraction of useful products from the data requires a number of separate conceptual steps, which will be different for each satellite. For the polar-orbiting satellites, a navigation model is used to establish the position of the satellite above the earth and the effects of the scanning geometry of the imaging instrument. The position of the pixels within the image from operational geostationary satellites will depend upon the scanning of the imager only. This knowledge permits the mapping of the image and the Earth's coordinates to be generated.

The raw satellite data stream must be calibrated from arbitrary instrument "counts" into physical quantities. For example, the basic imagery products will be:

Calibrated brightness temperatures (low clouds) albedo
Location of fog/low cloud
Sea-surface temperature
Cloud-top temperature
Calibrated brightness temperature (middle/high clouds) albedo
Location of convective cloud water vapor (6.7-μm imagery)
Global IR/visible imagery

The processed and reprojected images will be combined with model-based analyses, observational data, and geographical information on the users' systems.

At Bracknell several other efforts are now in progress in anticipation of new satellites and new sensors. One project, Meteorology Experimental Resource (MER), focuses on learning how to implement satellite data in "nowcasting" techniques; another group applies expert system tools using high resolution lightning detection system, radars, and satellites with mesoscale convective cloud models to predict thunderstorms. The investigators developing these methods use real-time data at interactive work stations, much in the same way FRONTIERS and Autosat-2 evolved. Note that the complexity and resulting errors in combining data from different platforms, as now done in the Autosat-2 system, would be reduced if EOS data were used. The EOS sensors would be measuring simultaneously in the same atmospheric columns. The knowledge gained from such measurements would improve the understanding of the phenomena being studied and accelerate the development of a useful product. Assume the Bracknell study in progress to improve thunderstorm prediction over the British Islands had real-time data available. (In Table 2, thunderstorms would be within the category of Mesoscale Convective Processes.) The sensors providing data would most certainly be LIS, the sure indicator of thunderstorm activity. For precursors and information at the time and place of the storm, the AIRS/AMSU instrument will provide atmospheric stability data, profiles of humidity, total precipitable water vapor and cloud-top temperature. MODIS will provide information on the clouds, HIMSS will provide precipitation rates, cloud water, and temperature profiles. For steering purposes, LAWS will provide wind information.

From the above discussions and analyses the need for real-time data for the identified scientific topics has been shown and, in some cases, with reference to specific EOS sensors. The EOS instruments were also analyzed as to their capability to provide real-time data. All sensors described in the 1990 EOS Reference Handbook were considered in the analysis and are shown in Table 7 (along the top). The scientific topics/events identified that need real-time data are listed in Table 7 (in the left-hand column). The fully darkened circle in the table indicates the instrument can provide critically important real-time data. The half circle indicates the sensor is capable of providing significantly useful real-time data. The open circle means the EOS sensor provides supporting data as information to correct another sensor on the same satellite platform.

The assessment presented in Table 7 is based upon the science needs and the instrument developers performance capabilities. For Table 7, the specific capability of the sensor was not explicitly considered as to the feasibility to provide information in real time. That added complexity of the analysis will be discussed in Section 4.

## 4. ANALYSIS OF EOS SENSOR CAPABILITY FOR SUPPORT OF SCIENCE

In the preceding sections of this report examples have been given to show how EOS can be used to optimize research, accelerate model development, and improve operational prediction of environmental parameters. The theme throughout the report has been how EOS supports the research priorities of the national global change initiative. The research priorities were identified (Figure 2) by the Committee on Earth Sciences of the Federal Coordinating Council for Science, Engineering and Technology. The national and international global

## TABLE 7. ANALYSIS OF REAL TIME SCIENCE APPLICATION AND APPROPRIATE EOS SENSOR CAPABILITY

| Real Time Application \ EOS INSTRUMENT | AIRS/AMSU | ALT | GLRS | HIRIS | ITIR | LAWS | MODIS N/T | SAR | ACRIM | CERES | ENACEOS | EOSP | GGI | GOS | HIMSS | HIDRLS | IPEI | LIS | MISR | MLS | MOPITT | POEMS | SAFIRE | SAGE III | SCANSAT STIKSAT | SOLSTICE | SWIRLS | TES | TRACER | TRAMMR | XIE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Solar terrestrial (radiation/particle ionosphere) | | | | | | | | | ○ | | ○ | | ○ | ○ | | | ◑ | | | | | ○ | | | | ○ | | | | | ● |
| Mesospheric and stratospheric clouds | | | ○ | | | | | | | | | | | | | ○ | ○ | | | ○ | | | ◑ | ● | | | ○ | | | | |
| Polar ozone hole | ○ | | ○ | | | | ○ | | | | | | | | | ◑ | | | | ○ | | | ● | ● | | | ○ | | | | |
| Stratospheric warming | ◑ | | | | | | | | | | | | | | | | | | | ○ | | | ● | ○ | | | ○ | | | | |
| Subvisible cirrus | | | ◑ | ○ | ○ | | | | | | | ○ | | | | | | | ○ | | | | | ○ | | | | | | | |
| Volcanic gas or particulate plumes | ○ | | ○ | ◑ | ○ | | ● | | | | | ○ | | | | ○ | | | ○ | ○ | | | ○ | ○ | | | | ○ | ◑ | | |
| Transport desert dust forest fire smoke and acid deposition | | | ○ | ◑ | ◑ | ○ | ● | | | | | ○ | | | | | | | ○ | | ○ | | | | | | | ○ | ○ | | |
| Arctic haze Ice leads | | | ○ | ◑ | ○ | | ○ | | | | | ○ | | | | | | | ○ | | | | | | | | | | | | |
| Pollution-ocean and troposphere | ○ | | | ○ | ○ | | ○ | | | | | | | | | | | | | | ○ | | | | | | | ◑ | ● | | |
| Ocean productivity (blooms) | ○ | | | ◑ | ◑ | | ● | | | | | | | | | | | | ○ | | | | | | | | | | | | |
| Mesoscale convective complexes | ◑ | | ○ | ○ | ○ | ◑ | ◑ | ○ | | ○ | | ○ | | | ● | | | ● | | | | | | | | | | | | ● | |
| Floods | ○ | | | ◑ | ◑ | | ◑ | | | | | | | | ○ | | | ◑ | | | | | | | | | | | | ◑ | |
| Typhoons/Hurricanes | ◑ | | | ○ | ○ | ◑ | ◑ | ◑ | | | | ○ | | | ● | | | ◑ | | | | | | | ● | | | | | ● | |
| Icebergs, ice sheet dynamics | | ◑ | ● | ◑ | ◑ | | ○ | ● | | | | | | | ◑ | | | | | | | | | | ○ | | | | | | |
| Look ahead or correction synergisms | ● | | | | | | ● | | | | | ○ | | | | | | | ● | | | | | | | | | | | | |

LEGEND

● Primary Capability

◑ Secondary

○ Contributing Capability to primary or secondary sensors change policy is to expand international collaboration on research, data gathering, modeling and data exchange; EOS can play a major role in carrying out this policy by delivering usable data products for both near and long term scientific benefits.

To deliver these data products, the EOS instruments were categorized by what they measured and what relationship they have to other EOS instruments, in a synergistic or ancillary way, to enhance the products to users. Here synergism refers to the support the primary instruments provide to other instruments, and ancillary refers to support instruments that receive data directly <u>from</u> other instruments. The EOS users include research scientists conducting field studies; laboratory professionals developing models, analysis procedures, or prediction techniques; and, operational meteorology and oceanography centers. These scientists and professionals need real time data products from merged sensor data from remote areas of the world (ocean, polar regions, etc.) to analyze calculated parameter indices that change significantly within a short period of time or space.

Many ways are available to analyze real time complementary sensor contributions to the overall EOS mission and applications to broad science areas. The EOS instruments could be categorized by the Earth's geophysical system's technically identified "spheres" such as hydrosphere, lithosphere, cryosphere, or biosphere. Under hydrosphere are hydrology, meteorology, and oceanography topics. In view of the interdisciplinary aspects of the Earth's geophysical systems, a single EOS instrument usually supports simultaneously several scientific issues; for example, MODIS N/T alone or with other instruments such as HIRIS, HIMSS, AIRS/AMSU, and EOSP, operating synergistically or in an ancillary mode will provide data products for a wide variety of scientific disciplines. These disciplines include aerosols and clouds, weather prediction, hydrology, ocean biology, and terrestrial vegetation. The spheres approach to link science categories and EOS instruments was judged to complicate the analyses of science needs for real time EOS products. An analysis of the EOS instruments with this approach did, however, help to focus on candidate instruments where data products in real time would be of value to the broad international scientific community.

Since the interdisciplinary Earth science topics were not easily categorized by traditional disciplines, another analysis was tried using processes as the grouping criteria. The processes may be labeled as thermodynamic, dynamics, radiation, etc. Table 8 is a summary matrix using the processes approach to categorization. The results of this analysis were useful, particularly in identifying alternative sensor combinations or substitutions for science products; however, other considerations for grouping and prioritization of the science topics and EOS instruments should be examined. Specifically the basic criteria for grouping a prioritization is as follows:

(a) Does the data respond to a high priority item of the U.S. Global Change Research Program?

(b) Will the research lead to better parameterizaton of geophysical, chemical, or biological variables that are (or should be) used in climate predictions?

(c) Will the EOS sensors have the capability to observe critical parameters?

(d) Will the research have early pay-off potential by using real time EOS data?

(e) Can the EOS instruments provide zero order or higher information to an onboard computer and allow processing to level 2?

(f) Will the data rate be within the EOS system's design for onboard processing and transmission to the ground?

From the real time science applications shown in Table 7, note that key EOS instruments for obtaining data from the top of the troposphere up through the stratosphere to the mesosphere are the limb scanners, e.g., SAGE III. The pollution events and subsequent transport are often best observed by multispectral instruments, e.g., MODIS, HIRIS, or TRACER. Tropospheric processes such as mesoscale convective cloud clusters require a sounder, HIMSS, or AIRS/AMSU. Solar-terrestrial studies require x-ray and particle detection

TABLE 8. EOS MEASUREMENTS FOR REAL-TIME/SCIENCE SUPPORT

| Category of Parameters Observed / MEASUREMENT SUPPORT | PRIMARY | ANCILLARY USEFUL INFORMATION | SYNERGISTIC SUPPORT |
|---|---|---|---|
| Thermodynamic (Temperature, Pressure Atmospheric chemistry) | AIRS/AMSU SAGE III | HIDRLS | AIRS/AMSU, EOSP, GLRS, HIRIS, ITIS, MLS, MODIS, TES |
| Dynamic (winds, currents) | SCANSCAT | ALT LAWS SAR SWIRLS | AIRS/AMSU, AMSR |
| Radiation (reflectance, solar visibility) | CERES XIE | ACRIM EOSP POEMS SOLSTICE | MISER, MODIS, TES |
| Physical (topography, cloud particles) | SAR GLRS | CERES LIS TRACER | ENACEDS, GOS HIMSS, HIRIS IPEI, ITIR, MIRS |
| Biological (ocean productivity, vegetation) | MODIS | AIRS HIRIS | GLRS, HIRIS ITIR, SAR |

instruments (e.g., XIE), and, finally, the ice systems are best observed with microwave instruments, e.g., EOS-SAR or HIMSS.

The many science events and processes shown in Table 7 were further consolidated and prioritized, as listed in Table 9. The five science groups resulted from the analyses presented in the preceding sections. Those analyses included informal discussions with many scientists in the United States and Europe, including many of the EOS instrument principal investigators. Each of the science events and processes discussed were determined to need EOS data for gaining fundamental new knowledge and improve predictions of environmental conditions.

Table 9. Science Priority Groups

| Priority | Group | Science Topic |
|---|---|---|
| 1 | Stratospheric Events and Processes | Mesospheric and Stratospheric Clouds<br>Polar Ozone Hole<br>Stratospheric Warming<br>Subvisible cirrus |
| 2 | Pollution Events and Transport | Volcanic Gas and Dust Plumes<br>Transport of Desert Dust, Smoke, Acid Depositions<br>Arctic Haze/ Leads<br>Oil/Chemical Spills in/on Water<br>Toxic Biota Blooms |
| 3 | Tropospheric Events and Processes | Typhoons/Hurricanes<br>Mesoscale Convective Complexes<br>Floods |
| 4 | Solar-Terrestrial | Solar Radiation<br>Particle Effects<br>Ionospheric Reactions |
| 5 | Ice Systems | Ice Sheet Dynamics<br>Icebergs |

In addition to the science and technology needs, mention should be made of the public interest shown in the five science groups. Properly addressing the public interest will assist funding justification for EOS. Societal benefits from near time EOS-derived advancements in science and science applications include:

- Explaining the reported stratospheric ozone depletion.

- Monitoring pollution transport and production of acid rain.

- Improving the prediction of hurricanes, snowstorms, and other tropospheric weather phenomena.

- Understanding how solar variability impacts weather and climate change.

- Applying quantitative analysis of ice systems to global change.

For each of the five groups potential exists to fulfill science/technology needs and enhance early EOS programmatic success from real time application of satellite data. Mapping of stratospheric ozone is an ongoing effort, for example, with plans to continue by orbiting new Total Ozone Measuring Spectrometers (TOMS) on different vehicles, including a Soviet satellite. An explanation of the ozone changes requires, however, detailed temporal and spatial observations of not only ozone, but the vertical structure of other changing atmospheric constituents, including polar stratospheric clouds. To explain the ozone depletion and ozone hole in the stratosphere, intensive observational programs have used aircraft vectored on the basis of near real-time data from a limb scanning instrument SAGE II. The next generation limb scanning instruments (SAGE III—scheduled for EOS and the Polar Ozone Aerosol Measurement instrument—scheduled for 1991 or 1992 launch on a French satellite) have improved capability for real-time transmission of data from the satellites. These instruments will greatly enhance the ability of future field campaigns to explain stratospheric ozone changes.

Similarly, the routine monitoring of pollution in the atmosphere and in the oceans, from satellites, will first require knowledge gained from complex campaigns employing both aircraft and ships. Several ocean field experiments are planned soon after the 1991 launch of the European earth observing satellite ERS-1. Again, the results from the field experiments would be significantly enhanced if specific data from a satellite was transmitted in real time to the field expedition scientists; for example, the specific identifying data for a particular type of pollutant requiring ocean characteristics may be derived from an onboard computation yielding an index from a mixture of several sensor channels.

The use of real-time data from satellites has been shown to be helpful in accelerating the development of prediction models for weather events. Models can be simplified if data from an EOS sensor is predetermined onboard the spacecraft for assimilation into a model; for example, a model designed to predict precipitation could receive directly from a passing satellite, in real-time, an index (precipitable water) that was generated onboard the satellite from a mixture of several sensor channels.

Following this type of rationale, the EOS instruments were analyzed for spatial/spectral resolution, spatial coverage, coincident support capability, data rate, and data processing requirement, and then matched to the science topics related to the real time applications. The result is the matrix shown in Table 10, which also highlights the importance of the instruments in the pursuit of the science topic. The legend in Table 10 explains the underlining; for example, a heavy underline indicates that instrument was judged to be of the highest priority for that science topic. In the assessment process, the assumption was made that the instruments could provide an onboard processor for level 0 signals and sensor channel mixing to produce in real time an index for ground user applications. Other benefits from onboard functions, for real time capability will include calibration and evaluation, channel mixing, correction, look ahead (to cue other sensors), and tracking of special events.

Many of the instruments are now being designed to accomplish some of these tasks but only on an instrument-to-instrument basis. The provision of the

TABLE 10. ANALYSIS OF SCIENCE GROUPS AND EOS SENSORS

| | Stratospheric Events/Processes | Pollution Events/Transport | Tropospheric Events/Processes | Solar Terrestial Effects | Ice Systems |
|---|---|---|---|---|---|
| Primary EOS Instrument(s) | SAGE III, SAFIRE | MODIS, MISR, TRACER | HIMSS, LIS, SCANSAT | XIE | GLRS, SAR |
| Secondary EOS Instrument(s) | AIRS/AMSU, GLRS, HIRDLS | HIRIS, EOSP, ITIR | AIRS/AMSU, MODIS | IPIE | ALT, HIRIS, ITIR HIMSS |
| Contributing EOS Instrument(s) | HIRIS, ITIR, EOSP MISR, SWIRLS | AIRS/AMSU, GLRS HIRIS, MLS, MOPPIT TES | GLRS, CERES, EOSP | ACRIM, ENACEDS, GGI, POEMS, SOLSTICE | SCANSAT, MODIS |

Priority

Important

Supporting

onboard processing capability is critical, however, since detailed user requirements cannot be determined 10 years ahead and since the sensor characteristics may change. Consequently, these reasons and the basic science needs support the argument that for EOS to be a true research tool, a requirement for real time, onboard adaptable processing also exists. The data needs of the research community during the 5 years of an EOS instrument's life are uncertain. A fundamental premise affirms that science data needs change as new knowledge is acquired. The data needs perceived by the principal investigators in the 1990 timeframe will most certainly change before the first EOS launch in the late 1990s. Even more certain is that, during the 5-year life of the instrument, the research scientists will require changes in the data they wish to receive—changes that may only be possible if an onboard processing capability is available.

The analysis of the EOS instruments for determining primary candidates to enhance science efforts with onboard processing considered the users capability to receive data in real time. The instruments shown with the heavy underline in Table 10 are the primary candidates, and (for the purposes of this study) the present capability of High Resolution Picture Taking (HRPT) receivers (664 Kbs) was used as the approximate data rate threshold. This consideration eliminated the instruments listed in Table 11 (from Appendix A, Table 5) as possible primary support sensors. The HRPT data rate allows small receiver antennae to be used whereas the 100 Mbs Landsat station, or currently being considered 15 Mbs downlink for EOS, requires significantly larger receiver antennae.

TABLE 11. High Data Rate EOS Instruments

| | | |
|---|---|---|
| AIRS/AMSU | MISR | SAFIRE |
| HIRIS | MLS | SAR |
| ITIR | MODIS-N | TES |
| LAWS | MODIS-T | TRAMMR |

Unfortunately, an instrument such as LAWS, which is excellent for many merged data products and user applications, was judged to exceed the envisioned cost effective onboard processor capability. LAWS, however, is a valuable new sensor that will advance numerical weather prediction and provide important information on atmospheric wind and turbulence. The challenge is how to make the perishable information derived from LAWS available in near real time to commercial customers. SAR is probably the best tool for studying ice dynamics, generation of leads, and flow ice (marginal ice and icebergs), but again, the data rate was assessed to be a problem for onboard processing. In addition to high data rates, these instruments were essentially "stand alone" instruments due to their size or power requirements, and, consequently, could not be considered in the analysis of merged data products or in the role being supported, or supporting other EOS instruments on a common vehicle.

The analysis has now narrowed the selection to six primary EOS candidate instruments so that if onboard processing were available, these instruments would definitely raise the EOS mission success expectations. The instruments and their resolutions (footprints) are listed in Table 12.

## 5. ENHANCEMENT OF EOS MISSION WITH ONBOARD PROCESSING

The instrument selection shown in Table 12 was based upon many judgments resulting from analyses of the sensors and discussions with investigators; however, the data rate or requisite data processing weighed heavy in the evaluation. Basically the instruments were divided into classes, those a LANDSAT station could process (up to 100 Mbs), and a second category for those that could downlink to an HRPT receiver at 0.664 Mbs or less. The dropping of high data rate (greater than 100 Mbs) instruments for real time onboard data processing is the reason, for example, that SAR does not appear later in this report under the ice system category in Table 13. Data rates for all EOS 1990 instruments are listed in Appendix A, Table 5.

### 5.1 Onboard Processing

The six instruments judged to be prime candidates to advance science with onboard processing are SAGE III, TRACER, HIMSS, LIS, SCANSAT, and XIE. A discussion of these instruments and their contributions to the success of the EOS mission will follow.

The instrument (determined from the various analyses) to be primary for the stratospheric events is SAGE III. The stratospheric category of research extends upwards to the interaction with the mesosphere and downwards to

TABLE 12. SUMMARY OF RESOLUTION DATA FOR SELECTED EOS INSTRUMENTS TO ENHANCE EOS MISSION WITH ONBOARD PROCESSING

| Science Topics | Primary Instruments | Resolutions Horizontal (km) | Vertical |
|---|---|---|---|
| Stratospheric Events and Processes | SAGE III | na | 1-3 |
| Pollution Events and Transport | TRACER | 20-300 | 3-4 |
| Tropospheric Events and Processes | HIMSS | 10 | 5-50 |
| | LIS | 10 | na |
| | SCANSAT | 25 | na |
| Solar-Terrestrial Effects | XIE | 40-240 | na |
| Ice Systems | HIMSS | 10 | 5-50 |

the interaction with the troposphere. The stratosphere is probably the most important layer of the neutral atmosphere to gain understanding of global changes as related to climate. At the interface with the troposphere are the newly discovered subvisible cirrus clouds, which are not factored into climate change radiation or dynamic circulation models. Higher in the polar night stratosphere are the polar stratospheric clouds, which (as already discussed) are believed to be important to the reported ozone depletion and development of the so-called ozone hole. Many atmospheric scientists are developing dynamics and chemistry models for the stratosphere in the attempt to understand and predict ozone stratospheric processes, including ozone change. Earlier in the report, the use of satellite data in near real time for the ozone hole field investigations was described. The system created for supporting the field campaigns with satellite data was a credit to the scientists involved, but if the key satellite had onboard processing and real-time data transmission, the complex communication/computer network and time lost would have been eliminated. SAGE III has the potential to transmit directly to field campaigns. Note that the Polar Ozone Aerosol Measurement II (POAM II) instrument, scheduled to be launched in 1992 or 1993, has the capability to transmit its data (very similar to SAGE III channels) directly to fixed or mobile receivers. For certain parameters, such as the important water vapor profile over the polar regions, a need exists to use properly the signals from the pairs of channels. The feasibility of adapting those algorithms for an onboard processor should be pursued.

SAGE III promises to be an excellent instrument. It will be self-calibrating and can measure parameters from the troposphere to near the mesosphere. The instrument has the capability to measure aerosol plumes from volcanoes and cirrus clouds. Model developers of stratospheric aerosols and transport, scientists investigating subvisible cirrus with ground-based lidars, and mesospheric cloud investigators planning rocket launches need SAGE III data. Specifically, a need exists for SAGE III to be available in real time and for SAGE III to have the ability to change channel mixing to study changing phenomena. For these reasons, having a processor on the satellite with appropriate SAGE III algorithms installed would be an asset to the EOS program.

Pollution events and transport of pollutants are major concerns of the environmental science community and the public. In recognition of these concerns, NASA has planned a real-time data assimilation and verification system for a Measurement of Air Pollution from Satellite (MAPS). As part of MAPS, a tropospheric carbon monoxide shuttle experiment is scheduled for 1992. Carbon monoxide (CO) plumes in the atmosphere may be from either natural or anthropogenic sources. The major natural source is from the oxidation of methane, while burning associated with industry and agriculture is believed to be the major anthropogenic source. The real time (MAPS) experiments planned for the shuttle will provide valuable information for the design of Tropospheric Radiometer for Atmospheric Chemistry and Environmental Research (TRACER), the instrument which this study determined was the primary EOS instrument for pollution event measurements.

TRACER can measure global atmospheric CO distribution, including the vertical profiles in the troposphere. This measurement is accomplished by using both the fundamental CO band at 4.6 μm and the 2.3-μm CO absorption band. To improve the CO measurement, nitrous oxide and methane information is used. The present TRACER design will have the capability to process (within the instrument) the appropriate channel mixture and have available real time CO data for transmission to users. The users of TRACER products range from transport model developers in laboratories to weather centers responsible for predicting severe weather. Natural mesoscale convective cloud systems pump CO plumes into the upper troposphere and stratosphere, which will be detectable by TRACER. The CO generated by natural and anthropogenic sources has a lifetime of weeks to months, which presents problems for mapping specific plumes that merge with other plumes. Synergistic use of data from other instruments (such as high resolution infrared channels) with onboard processing will facilitate the identification of specific plumes in real time. Cloud contamination is another problem when measuring tropospheric CO from space. With simple cloud detection algorithms, using Moderate-Resolution Imaging Spectrometer-N (MODIS-N) data, onboard processing could merge MODIS and TRACER products to produce (in real time) superior CO information to ground-based users. Users of TRACER real time onboard processed products will include field experimenters using aircraft to measure in situ pollution plumes. With real time information, the aircraft could be vectored directly into plumes to collect data that might otherwise be missed, thereby saving many hours of flying time.

The contemporary success of the SSM/I instrument is the result of good planning and flexibility in design. The High-Resolution Microwave Spectrometer Sounder (HIMSS) is the next generation SSM/I with greater resolution, and an opportunity is available now to plan for onboard processing. The SSM/I experience showed that during calibration and validation changes in the coefficients of relatively simple channel mixing algorithms greatly improved data usefulness. Simple reprogrammable algorithms in an onboard process will be of immeasurable value to the model developer in the laboratories. The computation of water vapor or cloud water over oceans is a good candidate for onboard processing. At present this information can be obtained from an SSM/I linear regression type algorithm using signals from several channels. Many algorithm would be similar to the following one for water over the ocean:

$$\text{Water Vapor (kg/m}^2) = C_0 + C_1 \quad S_{19} + C_3 \quad S_{22} + C_4 \quad S^2_{22} + C_5 \ S_{37}$$

where $C_0$, $C_1$, $C_3$, $C_4$ and $C_5$ are coefficients that, from experience, changed from the prelaunch hypothesized values to statistical values obtained during the calibration and validation phase of SSM/I. The $S_{19}$, $S_{22}$, etc., are generic representations of the voltages from the 19-GHz, 22-GHz, and 37-GHz channels. Similar algorithms for other nonlinear versions will be developed for the HIMSS instrument and are adaptable for installing as reprogrammable algorithms in an EOS onboard processor, such as has been proposed for the Information Sciences Experiment System (ISES). A similar algorithm to retrieve the same information over land requires further development and probably a mixture of data from another instrument, such as the Moderate-Resolution Imaging Spectrometer (MODIS). MODIS can provide the necessary background cloud, ice, and vegetation data for the HIMSS water vapor algorithms. Merging signals from sensors in contemporary satellites to enhance or create environmental data is a strong asset of EOS. EOS could be a leader in demonstrating this capability. A capability that will evolve from EOS research scientists using real-time data from onboard processors will chart the course for operational environmental satellites for the 21st century.

HIMSS designers can also exploit the experience of the SSM/I investigators in determining marine wind speeds. The SSM/I simple channel differencing algorithms are compromised, however, whenever heavy clouds or rain occurs. Again EOS has the capability to improve, if not eliminate, this SSM/I shortfall by using other sensor channels to adjust the wind speed algorithms for clouds and precipitation. The resulting wind speed data would then be available for direct transmission to field experimenters, model developers, or for operational use by ships at sea. Improved wind speed information at high latitudes would be welcomed by model developers in Scandinavia who are trying to improve polar low (Arctic hurricane) predictions. HIMSS, like its SSM/I predecessor, also has the capabilities to measure Arctic Ocean ice and ice characteristics wherever they are found. Of interest, the original SSM/I algorithms for ice were not good, but the Atmospheric Environment Service (AES) of Canada used SSM/I data and coincident corroborative data (including airborne radar) to refine the sea-ice parameterization algorithms. This significant achievement would not have been possible without real time SSM/I data flow to the algorithm developers in Ottawa. Again, as with other SSM/I algorithms, the possibility exists to tailor them for HIMSS, and they can be installed in an EOS onboard processor such as ISES. The HIMSS instrument could take the new data stream and use the simple algorithms, as is now being done, to supply the SSM/I data tapes to the research community. Onboard processing may not produce the highest research quality data possible, but it will make the data immediately available to scientists for vital time dependent research investigation and to operational users, or alert another sensor to switch into a different mode or point at a specific location.

HIMSS has onboard processing potential for both channel mixing of all HIMSS channels, but also the ability to use information from other EOS sensors to generate in real time usable products for tropospheric or ice system events and processes.

Numerous candidates are available for HIMSS merged data products being generated by an onboard processor. Two areas are highlighted in Table 12; other potential onboard algorithms include the precipitation rate for hyrodology, cloud water and water vapor for temperature profiles, ocean roughness for wind estimation, a sea surface temperature algorithm with corrections for sea surface roughness and atmospheric column, and ice/water discriminator and algorithms tailored for Arctic Ocean ice for identification of leads (open water) in the ice from clouds or aerosol plumes.

For centuries scientists have published hypotheses involving the influence of solar variability on weather and climate. The numerous statistical studies and theories have not, however, been universally accepted as the physical relationships linking solar variability to tropospheric weather has not been established. The X-ray Imaging Experiment (XIE) will provide the international scientific community interested in this problem with the first measurements of total particulate energy deposited in the Earth's global atmosphere, coincident with other measurements of thermodynamic, physical, and chemical changes. For example, does electron energy and atmospheric bremsstrahlung have an effect on clouds from mesospheric altitudes of 80 km to the tropopause? Also, cloud data from EOS instruments such as MODIS or HIMSS may link a corpuscular impingent event to cloud changes at a certain height, and SAGE III and other instruments may allow the linkage of ozone changes to particle precipitation events. Global lightning data from LIS could strengthen or weaken hypotheses that thunderstorm activity and solar variability are correlated. In addition, the global circulation of the stratosphere has been suggested by several authors in recent decades to be influenced by solar flares. The coincident data from SWIRLS or LAWS will be extremely useful for analysis in this research area. XIE will provide the scientists, who are monitoring and trying to model the variability of Earth parameters (e.g., short-lived thunderstorms or gravity waves breaking in the lower to middle atmosphere), with an entirely new data set to incorporate into these model developments.

For answers to questions on global change, XIE may well be one of the most important EOS instruments. EOS with XIE could open a credible new science discipline linking solar variability to global weather and climate change.

## 5.2 Summary of Applications for Onboard Processing

A summary of applications and potential uses of the onboard derived EOS data products can be divided into the four areas shown below. (Subsections 5.2 and 5.3 are based upon one author's previous evaluation and report on the meteorological applications for real time onboard processing of EOS data).

<u>Meteorological Uses of Onboard Derived EOS Data</u>

(a) Complementary Real Time Detection and Prediction Support

- Enhancement of prediction with known science and results
- Improvement of prediction with hypothesis and unknown results
- Value added when prediction has proven results

(b) Field Campaigns

- Mobile operations (airborne/ship)
  - Location and correlation of storms, ocean blooms, etc.
  - Validation of satellite instrument algorithms
  - Adjustment of onboard processor algorithms

- Fixed field experiments
  - Rocket probes
  - Radar, lidar, sodar campaigns

(c) Quick Response

- Events
  - Fires, dust storms, and industrial plumes
  - Volcanoes/gas and particulate plumes

- Research and development
  - Quick look for testing research hypothesis on model
  - Adjustments in real time to prediction models in development
  - Interactive introduction of ancillary data to models

(d) Positive Receipt of Data

- Remote or mobile sites
- Development laboratories
- Operational centers
- Foreign facilities

The discussions of the instruments listed in Table 10 described the rationale for their selection as important candidates for onboard processing and real-time transmission of products. The philosophy in the discussion of the instruments was reflected in the selection of all candidates listed in Table 10. One worthy of note is the Moderate-Resolution Imaging Spectrometer-N (MODIS-N). This instrument has many capabilities including the cloud detection capability for finding all cloud, cloud contamination (part cloud), or no cloud in the viewing path of an instrument. Algorithms are being developed for MODIS-N using infrared channels (3.7, 11, and 12 μm) and visible channels to automatically produce cloud detection information for other instruments or algorithms; for example, very high resolution infrared data algorithms for sea surface temperature require data to determine whether a pixel is cloud free. Another important instrument for a variety of applications is the combined Atmospheric Infrared Sounder and Advanced Microwave Unit.

Satellite cloud retrieval techniques have been evolving over the past three decades. Progress has been good since 1960 but not remarkable, and is still evolving. As has been noted earlier, clouds are the highest priority research topic for the National Global Change Program. EOS offers a unique opportunity to develop new and definitive algorithms for cloud products such as the following:

- fractional coverage in a sensor field of view
- top, possibly base height
- optical depth, particle size, water/ice phase
- element size

Past and present cloud retrieval algorithms have used or are using approximately a dozen different infrared channels, all of these, plus visible and microwave channels, will be available for use from the various EOS instruments. The increased number of channels with, for the most part, improved spatial resolution on the EOS platform holds the best promise in over 30 years to close in on the satellite cloud/no cloud retrieval, which is even now a problem for the International Satellite Cloud Climatology Project (ISCCP). The accuracy of the cloud climatologies, compiled by ISCCP, is particularly important for global change studies.

The preceding discussions indicate the value added to the EOS project from onboard processing of sensor data to provide products in real time. ISES, now being investigated at NASA Langley Research Center, will be capable of providing a value-added component. An ISES-like system onboard a space vehicle with many complementary sensors will improve the performance of individual sensors by exchanging data; it will also enhance the mission by facilitating onboard merged products for direct transmission to the user community. The ISES design concept would not interfere with the purpose of a single instrument nor the primary objectives of the mission; that is, any data processing by ISES will be accomplished in parallel with the normal operational flow of data. ISES will be subordinate to operational control systems and any experiments (e.g., algorithm changes) performed using ISES would not risk corruption of any data in the normal flow of data to the primary ground stations. The data received at the primary ground stations would always be available for sophisticated analysis and archiving. In the following paragraphs, the applications of ISES-type products are discussed.

Complementary Real Time Detection and Prediction Support. In view of inherent advantages (high spatial and spectral resolution) and disadvantages (low temporal resolutions and limited coverage) of EOS data, a prime utility for real-time data lies in its complementary impact on operational forecasting. While the operational GOES, GMS, and METEOSAT satellites provide the routine real time high temporal and spatial coverage, the EOS sensors can provide the multispectral, high resolution data, which can periodically complement the operational data with previously undetected characteristics of a meteorological situation. An EOS pass over a known mesoscale convective complex (MCC) could, for example, provide the ice/water determination, accurate cloud top and temperature data, droplet size distribution, rainfall/liquid water content (LWC) estimates, and surrounding wind field data needed to predict more accurately the development stage, movement, and severity of the MCC. The continued use of these complementary data should also provide unexpected improvements in the forecasts based on operational experience, and the proven results will then create a greater demand for data and favorable recognition of EOS benefit to the public.

Field Campaigns. The greatest perceived need of the research community for EOS data is in the execution of planned field testing, with the most urgent requirement coming from those with mobile measurement platforms, such as aircraft or ships. The ability to direct, in real time, the mobile platforms to the specific area requiring in situ data collection, and to provide immediate validation of satellite-aircraft data correlation is significant. The latter is of particular importance in the validation of satellite data processing algorithms for such detailed measurements as aerosol/droplet size distributions. Also, real-time or near real-time data are needed to meet the rapid response requirements for events, such as fires, dust storms, and volcanic eruptions. Not only general location and plume movement data are needed, but detailed information concerning the most dense or most complex areas is often required for direction of the aircraft. Locating and tracking volcanic plumes is not only a scientific task but, as will be noted under "quick look," is also important for civil aviation. To develop detection and prediction techniques, the requirement exists for real-time data from EOS for mobile platforms in the field. In addition, real-time data is a prerequisite for other successful investigations such as ionospheric probes or a rocket from a fixed site to obtain in situ microphysical measurements above aircraft altitudes, such as mesospheric clouds at altitudes of 85 km. Optimizing rocket probe launches with onboard processing capability on EOS vehicles could represent a significant cost savings and raise scientific achievements.

Quick Response to Events. EOS with an ISES-type capability can transmit quick look information to science teams validating or improving satellite instrument calibrations or user products at development laboratories such as the National Oceanic and Atmospheric Administration (NOAA), Forecast Systems Laboratory, or the Department of Defense (DoD) environmental laboratories. The DoD laboratories, where prediction models are continually being developed, include the Army Atmospheric Laboratory, Navy Oceanographic and Atmospheric Research Laboratory, and the Air Force Geophysics Laboratory. These models range from planetary boundary layer aerosol and smoke models to ionospheric behavior predictions and satellite altitude drag models. The quick look capability will provide the opportunity to adjust model parameterization without waiting days or months for coincident satellite data. Many contemporary prediction models are being developed to have the ability for assimilating data from satellites and from research or reconnaissance aircraft; for example, updating computations for a position fix on the eye of a hurricane, or polar low, can be extremely valuable.

The quick look capability has other research and direct use applications. A direct use of real time EOS data will be for civil aviation in the detection of aerosol conditions, turbulence, and volcanic plume advisories. In recent years commercial aircraft entering invisible, or visible, volcanic plumes have had all engines fail simultaneously. In one case an airliner entered an invisible gas cloud that eliminated the oxygen supply needed for combustion, resulting in the aircraft plummeting 25,000 ft before engine restarts were successful. In another case a commercial airliner's controlled flight path brought it through a visible volcanic dust cloud. All engines failed but again the aircraft had sufficient altitude to recover and land safely. EOS has the capability with onboard processing to provide real-time information on volcanic plumes.

The quick look capability can be used to calibrate instruments, adjust collection methods and areas, and add additional measurements to the data collection program. While most data collection, analyses, and field programs have been planned over a long time, seldom does one expect to have anticipated all the questions that will arise during data analysis. The value here is the ability to correct for unforeseen circumstances during data collection and be able to transmit these data products in real time to field campaign or laboratory scientists anywhere on Earth. EOS with onboard processing, such as ISES, will have quick look rapid adjustment capabilities for researchers and, when appropriate, for operational needs.

Positive Receipt of Data. Positive receipt and control of data is a general concern of scientists. A scientific team in the field cannot wait hours or days for data to make real-time decisions. A laboratory scientist developing a new model desires the ability to work with data interactively. The operational professionals responsible for hurricane forecasting or other life threatening phenomena have stated their need of EOS real-time data, but the value is indicated by the experience at the Joint Typhoon Warning Center, where having preliminary non-validated SSM/I data was indeed useful. Although the present planning for EOS will supply worldwide access to the data within days, concern has been expressed by non-U.S. investigators about the communications necessary for them to receive the data. A direct real time downlink for some of the data would be suitable to ensure receipt of certain critical data and allow for immediate use in their local area.

Scientists with experience conducting field experiments involving mobile in situ data-gathering platforms have expressed the greatest need for real-time data satellite products. The second group indicating the need for real-time data was composed of those with experience developing prediction models in the laboratory and those who have used data from research satellites for operational forecasts.

## 5.3 Potential Experiments

The value added to the EOS project by sensors mutually supplying real time merged data products to the international science community, laboratory scientists, and field experimentalists has been previously demonstrated in this report. Usually this feat was accomplished by using an example of some experiment. In this report, direct prediction experiments that could benefit from real time complementary data support have been discussed only briefly. Several potential experiments will now be discussed in some detail to illustrate how EOS sensors can be used to advance the performance of prediction techniques and field campaigning.

<u>Complementary Real Time Prediction Support</u>. The five complementary real-time forecasting support experiments using EOS data products are:

(a) Integrated cloud classification and evaluation.
(b) Improved profiles of temperature, water vapor, and winds.
(c) Characteristics and occurrence of cirrus, subvisual cirrus, and mesospheric (noctilucent) clouds.
(d) Improvements in tropical storm observation and forecasting.
(e) Increased accuracy in surface visibility from data sparse areas.

Each of the hypothesized real time forecasting support experiments listed above will be discussed with reference to EOS:

(a) Integrated cloud classification and evaluation: The increasing resolution and coverage of the satellite sensors and the extensive data requirements of the many analysis and forecasting models have established the need for computerized handling of satellite data. This process requires a significant number of algorithms (Wielicki, 1989; Arking and Childs, 1985), beginning with the basic (but certainly not simple) cloud/no cloud algorithm. Whatever the wavelength (visual, IR, microwave), the definitive identification of cloud and precipitation areas is not trivial and often requires multispectral data analysis to successfully present the situation to the meteorologist. Shown here are examples of the specific wavelengths that could be required to be cross-correlated onboard and the resulting product downlinked for real time use. The ability of a meteorologist to accurately forecast the sensible weather parameters also may depend upon the knowledge of microphysical features of the meteorological situation. The ice/water cloud content, droplet size distribution, liquid/water content (LWC) and precipitation spatial distribution, and detailed cloud top and temperature data are all elements derivable from EOS real-time data, and can influence real-time operational forecasting. The integration of the spatial and microphysical cloud data could provide the key complementary data set needed to enhance the forecast accuracy for many meteorological situations. The suggestion for onboard processing is the downlink of the individual bands referred to (priority of need is indicated) and the onboard processing results from three algorithms (to be modified by command) that merge the data from several sensors and provide the cloud classification and analysis results needed. The first algorithm would be an agreed standard to be maintained for consistency and comparison purposes while the other two would be used on a trial basis and be modified as analysis and application dictate.

INTEGRATED CLOUD CLASSIFICATION AND EVALUATION

| PARAMETER | BAND | PRIORITY OF NEED |
|---|---|---|
| 1. Cloud/No Cloud | 0.6 µm algorithms | 4 |
| (over land, water, snow and ice) | 3.7 µm black stratus (night) | 2 |
| | 1.6 µm snow/cloud (day) | 3 |
| | 18/37 GHz | |
| Coverage (fraction) & Size (cells) | Algorithms | |
| 2. Type (high cirrus/middle altocumulus/low stratus) | | |
| Ice/Water (stage of development) | 1.6 µm/0.75 µm | 3 |
| 3. Top/Base (temperature or backscatter) | 11 µm and 14 µm/Lidar* | 1&7/+ |
| 4. Optical Depth (Brightness) | 0.75 µm | 4 |
| Droplet Size Dist | 2.1 µm/0.75 µm | |
| Aerosol Size Dist/Correction | 0.5 µm/0.7 µm/Lidar | 5 |
| 5. LWC and Precipitation | 37&90 GHz/0.75 µm/LIS | |
| 6. Water Vapor | 6.7 µm | 6 |

SUMMARY DOWNLOAD: 8-12 bands plus 3 merged algorithms (MODIS, AIRS/AMSU, HIMSS, GLRS, LAWS, and LIS)

*indicates lidar data from GLRS, LAWS if available.

(b) Improved profiles of temperature, water vapor, and winds: A key factor in the accuracy of both the longer range (6-96 hr) and shorter range (0-6 hr) forecasting models and methods is the accuracy of the vertical profile data. Satellite derived profile data (see below), while providing broad spatial coverage, have been unable to match the accuracy of the rawinsonde balloon (RAOB) data. Now EOS offers the opportunity to approach the accuracy of the RAOB by using sensors with greater spectral resolution and by merging the data from several sensors. In addition to using higher resolution IR/MW sounders (AIRS/AMSU/HIMSS), by using lidar to pinpoint the planetary boundary layer (PBL) and the tropopause heights, for example, a significantly more accurate profile (Westwater et al., 1983) of temperature and moisture could be obtained for real-time application to short range severe weather, visibility, pollution, and surface wind forecasting. Also, the LAWS system offers the ability to greatly increase the coverage of wind profile data providing greater short range forecast accuracy as well as improved longer range forecast model accuracies. The downlink suggestions for an onboard processor would be a standardized profile from a merged data set and two trial algorithms for research application. This particular benefit is recognized by NOAA/NESDIS, and efforts to obtain a short circuit of the EOS-TDRSS-WSMR-GSFC link are being made to provide the data direct from WSMR to the NOAA/NMC facility at Suitland, MD.

Improved Profiles

PROFILES (Temperature, Water Vapor, Winds)

MERGED - AIRS/AMSU (8-14 $\mu m$) and HIMSS (50-60 Ghz) sounders plus information from other sensors.

SUMMARY DOWNLOAD: Profiles of temperature, water vapor, and winds from onboard algorithms, one standard, other trials for each profile.

(c) Characteristics and occurrence of cirrus, subvisual cirrus, and lower mesospheric (noctilucent) clouds: From a real-time perspective, the characteristics and probability of occurrence of particulates at high altitude are parameters of considerable interest for the reentry of the Space Transportation System (STS) and the National Aerospace Plane (NASP). According to Covault (1988), these particles provide the potential for structural damage as well as forced deviation from a planned reentry path. If these particles have that potential, then an onboard processing requirement is needed for near real-time broad area measurements along and near the proposed reentry path. Ground based lidar measurements of subvisual cirrus have indicated that this upper air feature occurs routinely. With the normal 25-35 percent probability of occurrence for cirrus clouds and added effects of mesospheric (noctilucent) clouds, the potential probability of ice crystal cloud particulate interaction with the STS/NASP vehicles on reentry appears to be significant (Wylie, 1989). While more detailed analyses by recovery location and further investigation into the aerosol interactions with the STS/NASP airframes will size the problem more accurately, a potential real time observational need exists, associated with these high altitude features. The merging of lidar measurements with visual/IR imagery and apparent cloud-top temperature data may be able to identify the features needed for real time decisions related to reentry (see below). The suggested downlink information would be lidar high altitude return along with three algorithm products for continuing analyses.

CIRRUS, SUBVISUAL CIRRUS AND MESOSPHERIC (NOCTILUCENT) CLOUDS

(STS and NASP real time reentry decisions)

MERGED - LIDAR with MODIS (10.5 $\mu m$/0.65 $\mu m$) and AIRS (CO slicing)
(New 0.4-0.7 $\mu m$ algorithms)

DOWNLINK SUMMARY: LIDAR data and cloud particulate information from onboard standard and trial algorithms (LAWS, GLRS, MODIS-N, AIRS/AMSU and HIMSS)

(d) Improvements in tropical storm observation and forecasting: Since the lack of surfaced-based observations in the tropics makes the satellite the dominant observational platform for tropical meteorology, considerable information concerning tropical storm development and movement could be obtained from EOS data. Hurricanes/typhoons are relatively slow moving and can be easily tracked by geostationary and operational polar orbiting satellites; however, the detailed characteristics of the mass of the storm and the surrounding pressure, wind, temperature, and moisture fields govern the all important forecast track, and an onboard processor can provide these data. Since actions required to protect from storm damage take many hours of preparation, adequate warning lead time is required and real time updates of the detailed environment are needed; for example, the subsidence in the storm eye produces a warm core measurable from a satellite and can be used to estimate the minimum pressure, maximum winds, and overall storm intensity (Kidder et al., 1978). The surrounding cold cloud tops from overshooting cumulonimbus clouds also help define the intensity and locations of the more severe weather. Infrared sounder data with < 15 km resolution, coupled with lidar cloud-top measurements, should be able to provide these estimates. The precipitation areas, which are visually obscured, are particularly important since flooding is often the most significant consequence of a tropical storm. Microwave imager and lightning detector data should outline the areas and intensity of the precipitation. Finally, the dominant impact of the surrounding wind and pressure fields on the forecast track makes the satellite derived surface wind measurements vital for real time forecasting of storm movement. Both the scatterometer and microwave imager have capabilities in this area. Many of the sounder and imager algorithms are well known and viable for onboard processing; however, the interpretative nature of the microwave image and other requirements for spatial analyses will probably require significant level 2 data to be downlinked.

TROPICAL STORM OBSERVATION AND FORECASTING IMPROVEMENTS

- Eye Temperature (Press/Winds)—AIRS/AMSU, HIMSS (15 km res)
- Cold Cloud Tops—AIRS/AMSU, MODIS-N
- Precipitation (storm detection)—HIMSS/LIS/TRAMAR
- Winds (storm and area)—HIMSS/SCANSAT/SAR/LAWS

DOWNLINK SUMMARY: Level 2 and merged algorithm data for central pressure/max winds/storm precipitation potential.

(e) Increased accuracy of surface visibility from data sparse areas: The real time requirement for surface visibility (as impacted by the aerosol, water vapor and related temperature profile) is primarily from DoD. This requirement is for support to operations that would take place in areas without ground-based observations. Many military missions are affected by low altitude restrictions to visibility. The detailed spectral data from visual/IR imagery, coupled with lidar data of the aerosols in the boundary layer, should provide much of the information needed for immediate direct mission support and short-range forecasting (see below). The multispectral data from MODIS can provide some of the needed visibility information through extraction of optical depth data. Also, the lidar data should significantly improve the overall accuracy of the concentration and vertical distribution of aerosols by more accurate measurements of the planetary boundary layer.

DERIVED SURFACE VISIBILITY

(DoD Requirement—Data Denied/Data Sparse Areas)

- MODIS image data
  (background catalog)

- MERGED data (aerosols, near surface and profiles)

SUMMARY: Downlink surface index (snow, ice, forest, etc.) from MODIS or merged aerosol estimates from merged sensors in infrared, visible, and microwave channels from HIMSS and other instruments.

Field campaigns. Several examples of recent field experiments have already been discussed in this report; they include vectoring an aircraft into a polar low, directing aircraft for investigations of the ozone hole, and diverting research aircraft to make volcanic plume measurements. Others were mentioned using ships, or in one case, a planned Lagrangian drift experiment using a blimp. Clearly, EOS data products will be of great value for many field experiments.

Field testing with mobile platforms, especially aircraft, is the most apparent research requirement for onboard processed data. This group of experiments involves aerosol transport and relates to the improved ability to rapidly find a plume and be able to direct an aircraft into the appropriate area of the plume. This accomplishment allows the possibility for Lagrangian-type measurements over long distances, directing the aircraft from day-to-day to the appropriate altitude and location within the plume to follow the same parcel of air. For large meteorological features, such as areas of arctic haze or polar stratospheric clouds, accurate vectoring of the aircraft is also needed to rapidly find and traverse the cloud area. Another field test with special interest in real-time data is the Global Atmospheric Sampling Program (GASP), supporting the testing of laminar flow control for airfoils. Cirrus and subvisual cloud crystals are of particular concern since they break up the laminar flow across the aircraft wing (Davis et al., 1989). Consequently, successful tests must be flown in perfectly clear air (undetectable from normal meteorological satellite images), and onboard processed data can identify the appropriate test areas in real time.

The commonality within the examples discussed is the need for (a) real-time data flow to the user; (b) the EOS program to have the flexibility to handle the unexpected result; and (c) the ability to adapt the processing capability for real time applications.

## 6. CONCLUSIONS

The results of this study, which included an international informal community-wide survey, identified the groups that perceived the greatest need for real-time data. The theoretical (primarily academic) scientific community and the operational organizations did not see as strong a need as others for real-time data from EOS polar platforms, but for very different reasons. Most researchers see later receipt of the data as sufficient, while many in the operational community, whose mission performance depends upon real-time data, felt the limited spatial and temporal coverage negated the potential benefit for day-to-day operational use. The experimentalists and scientists involved in field testing, along with the technique developers for operational organizations, expressed the greatest interest and need for real-time data with onboard processing capabilities. These products could be provided by an onboard processor, such as ISES. This system is now being proposed for EOS by NASA Langley Research Center. ISES is a real time processing system of the type that will add value to the EOS project by facilitating onboard merging of data into products for direct transmission to the field or laboratory user. This onboard data processing will be accomplished in parallel with the normal operational flow of data and will not interrupt the planned delayed ground-based processing. The data products from an onboard system will be designed for rapid application for a variety of users and require less capable receivers than the primary receiving stations. The experimentalist conducting a field operation in a remote (e.g., ocean, polar) part of the world, or a foreign user, would be expected to have a limited data ingestion capability. An onboard data processing system will facilitate broad user access but at the same time increase onboard autonomy and security of the complete data set for transmission to primary ground stations.

> The experimentalists and scientists involved in field testing, along with the technique developers for operational organizations, expressed the greatest interest and need for real-time data with onboard processing capabilities.

The numerous examples presented of EOS data uses had two things in common. First, most, if not all, indicated that improved results would follow if direct-to-user flow of real-time information were available from EOS sensors. Second, due to the unpredictability of scientific discoveries, the results indicated significant potential for greater understanding if the EOS platforms had flexibility in measurement capability and data products—creating the need for onboard processing capability. The unpredictability of discovery not only applies to the changing needs of the scientists but is reflected in project management. Jewkes and Stillerman (1958) commented on flexibility in industrial research management, which applies to all research. More than 30 years ago they wrote the following:

> "The best person to decide what research work shall be done is the man who is doing the research. The next best is the head of the department. After that you leave the field of best persons and meet increasingly worse groups. The first of these is the Research Director, who is probably wrong more than half the time. Finally there is the committee of company Vice-Presidents which is wrong all the time."

The person doing the research is the one who will first recognize an unpredictable finding and accordingly adjust his algorithms and measurements to prove or disprove a possible discovery. With flexibility in research and measurements, the research objectives are more likely to be achieved. Also, Hitch and McKean (1978) advocated that the pursuit of a research objective along several paths saves money, time, and increases the chances of success. They cite the Manhattan project that had six methods concurrently under study, and the initially least promising one succeeded. They also noted that with greater uncertainty in the science, the number of alternate paths of research should increase. These comments from Hitch and McKean are translatable to EOS. The chances for success lie in the several methods or sensors for measuring Earth system variables and with the investigators with alternate approaches addressing priority global change science topics. Hitch and McKean make the case that focusing resources on only one alternative that fails is a waste. The unpredictability of scientific discoveries requires flexible approaches in the research, measurement systems, and management.

> The unpredictability of scientific discoveries requires flexible approaches in the research, measurement sytems, and management.

The central theme of this report has been the benefits EOS will bring to the international science community addressing global change issues. Since EOS instruments will not be in orbit until late in the decade and will be providing data well into the next century, the evaluation had to consider the well-known unpredictability of research findings.

The unpredictability of the when, where, and what will be discovered to be important in global change research led to the finding that for EOS to be successful, the design must have flexibility in measurement ability.

For fundamental science research in the field and model developers in laboratories, the unpredictability of discoveries led to another finding for EOS project success. That finding being the EOS need for real time, direct to user capability. The latter requirement suggests that instruments with low or medium data rates would be more useful in the earlier phases of the project, particularly during the refinement stage of algorithm development when field experimentalists or a ground truth network are used to improve data products.

These three factors—measurement flexibility, need for real-time data flow, and capability to adjust algorithms to enhance or possibly save the EOS mission—led to the requirement for onboard processing. This onboard processing will need the capability to provide merged data products, onboard sensor corrections, and the flexibility for scientists to change product or sensor correction algorithms.

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Considering only low and medium data rate instruments, the potential for onboard merged data products and sensor support to each were analyzed. The low data rate category is for less than 0.664 Mbs, the medium rate generally up to a few tens of megabytes, to possibly as high as 100 Mbs.

Table 13 summarizes the analysis of matching science needs to EOS instruments with low or medium data rates. In Table 13 the circle around a solid or half darkened symbol identifies the instrument(s) to have high potential for the indicated science use. The original list of over 30 EOS instruments has been reduced to six low and four medium data rate instruments that have onboard processing potential and, therefore, are likely to contribute to the early successes of the EOS project.

The strength of EOS contribution to the science community in the next quarter century has been demonstrated throughout this report. The key to that strength was also clearly shown to be a real time, direct to user capability. To optimize EOS data, the direct to user and onboard processing capabilities require assessment of the potential science productivity and mission success resulting fɿom these capabilities. The science productivity and EOS mission success has been shown in many ways in this report. The science, instrument,

TABLE 13. SUMMARY OF SCIENCE SUCCESS POTENTIAL WITH ONBOARD PROCESSING

| EOS INSTRUMENTS | LOW DATA RATE | | | | | | MEDIUM DATA RATE | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SCIENCE | SAGE III | TRACER | HIMSS | LIS | SCANSAT | XIE | MODIS | GLRS | SAFIRE | MISR |
| Stratospheric Events and Processes | (●) | | | | | | | ◑ | ● | ○ |
| Pollution Events and Transport | | (●) | | | | | (●) | | | ● |
| Tropospheric Events and Processes | | | (●) | ● | ● | | (◑) | ○ | | |
| Solar Terrestrial Effects | | | | | | (●) | | | | |
| Ice Systems | | | (◑) | | ○ | | ○ | ● | | |

Legend

Estimated potential for onboard processing to level 2 considering products and data rates

○ Circle around symbol indicates highest priority for science topic

Symbol

● Excellent

◑ Good

○ Fair

and data processing factors that were evaluated have been consolidated into Table 14. This table summarizes the evaluation of EOS instrument capability in contributing to the advancement of global change science topics and enhancement of EOS project success.

The sensor-by-sensor evaluations of the potential for onboard processing was based on essentially 1990 technology for developing a system such as ISES. This assumption is restrictive, as surely significant technological development will progress further in onboard processing software and hardware. Possibly an onboard processor by the turn of the century will be capable of handling even the extremely high data rates. On the contrary, sensor technology may advance and the present high data rate instruments will be designed, with new concepts producing lower data rate power and weight requirements. An example could be an improved lower data rate SAR that could replace HIMSS as the primary ice systems instrument.

The results of the evaluation of instrument potential for onboard processing are illustrated in Table 14 with the now familiar symbols. Here the symbol next to an identified instrument indicates a cumulative assessment of three factors: (a) onboard processing to level 2, (b) merged product potential, and (c) support to other sensor operations. SAGE has a solid circle symbol, for example, which means that it is judged to fulfill the above factors with an excellent rating.

For the most part the merged data products shown in Table 14 and explained by the footnotes are based on examples previously discussed in this report.

The support of instruments to each other is based upon information provided by the instrument descriptions found in the tables in Appendix A.

The analysis in this report, including the results summarized in Table 14, was influenced by informal conversations with principal investigators and many scientists in the United States and Europe. The scientists included those involved with the EOS project and others concerned with global change topics, model developers, and professional operational people.

TABLE 14. EVALUATION OF EOS INSTRUMENTS AND ONBOARD PROCESSING POTENTIAL CONTRIBUTION TO ENHANCE SCIENCE RESULTS AND EOS MISSION SUCCESS

| SCIENCE TOPICS / EOS INSTRUMENT EVALUATION | INSTRUMENTS WITH POTENTIAL FOR ON-BOARD PROCESSING: Primary | Secondary | Contributing | POTENTIAL MERGED PRODUCTS | SUPPORT TO OTHER SENSOR OPERATIONS |
|---|---|---|---|---|---|
| Stratospheric Events and Processes | SAGE III ● | GLRS ◑ | SAFIRE ○<br>AIRS/AMSU ○<br>HIDRLS ○ | Polar ozone hole dynamics (1)<br>Polar stratospheric clouds and chemistry (1)<br>Volcanic aerosol injection (2) | SAGE III → GLRS, AIRS/AMSU (aerosol location and correction) |
| Pollution Events and Processes | TRACER ● | MODIS ◑<br>MISR ○<br>GLRS ○ | AIRS/AMSU ○ | Volcanic ash plume and desert dust transport (3)<br>Nonvisible volcanic or combustion gas plume (4)<br>Phytoplankton ocean blooms (5) | TRACER ⇄ MISR, GLRS, AIRS/AMSU (vertical transport and profile)<br>MODIS → TRACER (source definition: fires, clouds, vegetation index, etc.) |
| Tropospheric Events and Processes | HIMSS ●<br>LIS ●<br>SCANSAT ◑ | MODIS ◑<br>GLRS ◑ | AIRS/AMSU ○ | Severe weather (tornado/flashflood) potential and cloud microphysics (6)<br>Hurricane positioning and intensity (7)<br>Ocean storm in-flow and intensity (7)<br>Lightning impact on global electric field (8)<br>Tropical lightning/Hadley cell/precipitation product (9) | HIMSS ⇄ SCANSAT (water in column to SCANSAT, and SCANSAT adds wind direction information)<br>MODIS → HIMSS, AIRS/AMSU (cloud contamination)<br>GLRS ⇄ HIMSS, MODIS, AIRS/AMSU/ (cloud top/aerosols and GLRS pointing) |
| Solar Terrestrial Effects | XIE ● | IPIE ◑ | SAGE III ○<br>SOLSTICE ○<br>HIDRLS ○ | Ozone chemistry (10)<br>Atmospheric electrical properties and clouds (11) | XIE ⇄ IPIE (source definition and response of ionosphere) |
| Ice Systems | HIMSS ● | GLRS ◑<br>ALT ○ | SCANSAT ○ | Arctic systems science, hydrological circle of Arctic Ocean Basin (12)<br>Snow/ice/sea discrimination and ice motion (13) | HIMSS → ALT, SCANSAT (water vapor corrections) |

LEGEND

Potential for onboard processing to level 2 and impact on merged or synergistic algorithms

● Excellent
◑ Good
○ Fair

TABLE 14. EVALUATION OF EOS INSTRUMENTS AND ONBOARD PROCESSING POTENTIAL CONTRIBUTION TO ENHANCE SCIENCE RESULTS AND EOS MISSION SUCCESS (continued)

FOOTNOTES:

(1) Polar stratospheric clouds and microphysics (SAGE III/GLRS/HIDRLS) and $O_3$ depletion rate chemistry products.

(2) Altitude, concentration, and size distribution of injected volcanic aerosols (SAGE III and GLRS) products.

(3) Transport, concentration, extent, particle size, distribution of volcanic ash and desert dust (MODIS/GLRS) products

(4) Gaseous and nonvisible plume detection (TRACER) and relation to particulate (GLRS/MODIS) plume products.

(5) Identification, event, transport of ocean blooms (MODIS/MISR) products.

(6) Cloud tops (GLRS, AIRS/AMSU), lightning (LIS), precipitation (HIMSS), ice/water and hydrometer size distribution (MODIS-- multichannels for severe weather (tornadoes/flashfloods) products.

(7) Hurricanes/polar lows have warm core eyes (often covered by clouds) correlated with pressure and wind extremes (HIMSS/AMSU), also ocean storm inflow (SCANSAT) provides location and intensity products.

(8) Global electric circuit rapid variation product from lightning discharges (LIS) and ionospheric/magnetospheric (IPIE) impact.

(9) Tropical lightning relation to Walker-Hadley circulation product from LIS-AMSU-HIMSS "hot tower" correlation.

(10) Stratospheric ozone ($O_3$) change products from SAGE III/HIDRLS/SOLSTICE, occurs with solar proton event (XIE); stratospheric ozone (SAGE III/HIDRLS) depleted by electron precipitation (XIE/IPIE).

(11) Middle atmosphere electric fields (XIE), lightning (LIS), clouds (HIMSS, MODIS, AIRS) and ionospheric variability (IPIE) for cloud products.

(12) Arctic systems science/coupled clouds (GLRS), precipitation (HIMSS) sea-ice (ALT, SCANSAT, HIMSS) for Arctic Basin hydrological cycle products.

(13) Ocean/atmosphere/ice modeling product using snow/ice (HIMSS) and ice/sea (ALT) discrimination, and sea ice motion (GLRS/SCANSAT).

The consensus is that EOS holds great promise in the next quarter century for its products to advance understanding of the Earth's process impacting global change. The study concludes that to fulfill this promise and accommodate the unpredictability of research discoveries EOS needs real time, direct-to-user data flow from onboard processing.

An EOS without real time, onboard data processing flexibility and direct-to-user capability could severely compromise the overall purpose of this 25-year project. The most important recommendation is that a real time adaptable downlink system, such as the Information Science Experiment System, be provided for each EOS platform.

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## REFERENCES


Arking, A., and J. D. Childs, 1985: Retrieval of Cloud Cover Parameters from Multispectral Satellite Images, J. Climate and Appl. Meteor., 24, 332-333.

Bengtsson, L., and J. Shuklu, 1988: Integration of Space and In Situ Observations to Study Global Climate Change, Bull. Amer. Meteor. Soc., 69 (10), 1130-1143.

Carlson, J. D., 1989: The Importance of Agricultural Weather Information: A Michigan Survey, Bull. Amer. Meteor. Soc., 70, 366-372.

Charlson, R. J., J. E. Lovelock, M. O. Andrea, and S. G. Warren, 1987: Oceanic Phytoplankton, Atmospheric Sulfur, Cloud Albedo and Climate, Nature, 326 (16), 655-664.

Coakley, J. A., R. L. Bernstein, and P. A. Durkee, 1988: Effect of Ship-Stack Effluents on the Radiative Properties of Marine Stratocumulus: Implications for Man's Impact on Climate, Aerosols and Climate, P. V. Hobbs, and M. P. McCormick (Eds.), A. Deepak Publishing, Hampton, VA, 253-260.

Committee on Earth Sciences, Our Changing Planet: The FY 1991 U.S. Global Changes Research Program, report accompanying the U.S. President's fiscal year 1991 budget, Committe on Earth Sciences, Washington, DC. (Can be obtained from U.S. Geological Survey, 104 National Center, Reston, VA 22092).

Covault, C., 1988: Ice Clouds Could Threaten Space Shuttle Reentry Safety, Aviation Week and Space Technology, 26 August 1988, 83.

Davis, R. E., D. V. Maddalon, R. D. Wagner, D. F. Fisher, and R. Young, 1989: Evaluation of Cloud Detection Instruments and Performance of Laminar-Flow Leading-Edge Test Articles During NASA Leading-Edge Flight-Test Program, NASA TP-2888, National Aeronautics and Space Administration.

Dirks, R. A., 1988: Genesis of Atlantic Lows Experiment (GALE): An Overview, Bull. Amer. Meteor. Soc., 69 (2), 148-160.

Emanuel, K. A., and R. Rotunno, 1989: Polar Lows as Arctic Hurricanes, Polar and Arctic Lows, P. Twitchell, E. Rasmussen, and K. Davidson (Eds.), A. Deepak Publishing, Hampton, VA, 155-177.

Fett, R. W., 1989: Polar Low Development Associated With Boundary Layer Fronts in the Greenland, Norwegian, and Barents Seas, Polar and Arctic Lows, P. Twitchell, E. Rasmussen and K. Davidson (Eds.), A. Deepak Publishing, Hampton, VA, 313-322.

Gloersen, P., E. Mollo-Christensen, and P. Hubanks, 1989: Observations of Arctic Polar Lows with the NIMBUS-7 Scanning Multichannel Microwave Radiometer, in Polar and Arctic Lows, P. Twitchell, E. Rasmussen, and K. Davidson (Eds.), Deepak Publishing, Hampton, VA, 359-372.

Hitch, C. J., and R. N. McKean, 1978: The Economics of Defense in the Nuclear Age, Harvard University Press, Atheneum Press, New York, 247-261.

Hoppel, W. A., 1987: Nucleation in the MSA-Water Vapor System, Atmos. Environ., 21 (12), 2703-2709.

Jeck, R. K., 1986: Airborne Cloud-Physics Projects from 1974-1984, Bull. of Amer. Meteor. Soc., 67 (72), 1473-1477.

Jewkes, J., D. Sawers, and R. Stillerman, 1958: The Sources of Invention, Macmillan and Company, Ltd., London, 138 pp.

Juckes, M. N., and M. E. McIntyre, 1987: A High Resolutory One-layer Model of Breaking Planetary Waves in the Stratosphere, Nature, 328 (13), 590-595.

Kidder, S. Q., W. M. Gray, and T. H. Vonderhaar, 1978: Estimating Tropical Cyclone Central Pressure and Outer Winds from Satellite Microwave Data, Mon. Wea. Rev., 10 (106), 1458-1464.

Langland, R. H., and R. J. Miller, 1989: Polar Low Sensitivity to Sea Surface Temperature and Horizontal Grid Resolution in a Numerical Model, Polar and Arctic Lows, P. Twitchell, E. Rasmussen, and K. Davidson (Eds.), A. Deepak Publishing, Hampton, VA, 247-253.

Leone, D. A., R. M. Endlich, J. Petriceks, R. T. H. Collis, and J. R. Porter, 1989: Meteorological Considerations Used in Planning the NEXRAD Network, Bull. Amer. Meteor. Soc., 70 (1), 473.

Midtbo, K. H., and M. Lystad, 1987: Forecasting Polar Lows Using a Numerical Mesoscale Model, Proceedings of the Symposium on Mesoscale Analysis and Forecasting, Vancouver, Canada, 17-19 August 1987, ESA SP-282, 487-490.

Mulligan, F., 1974: Oceanographic Factors Associated with New England Red Tide Blooms, Proceedings of the First International Conference on Toxic Dinoflagellate Blooms, Boston, MA, 4-6 November 1974, Sea Grant Program, Massachusetts Science and Technology Foundation, Wakefield, MA, 23-40.

NASA Goddard Space Flight Center 1990: EOS 1990 Reference Handbook, 256-267/20032, U.S. Government Printing Office, Washington, DC.

Newell R. E., A. G. Reschle, and W. Seiler, 1989: Carbon Monoxide and the Burning Earth, Scientific American, 86-88.

Post, M. J., and W. D. Neff, 1986: Doppler Lidar Measurements of Winds in a Narrow Mountain Valley, Bull. Amer. Meteor. Soc., 67, 274-288.

Rasmussen, E. A., and P. D. Aakjaer, 1989: Two Polar Lows Affecting Denmark, Vejert (special English issue), Danish Meteorological Society, Copenhagen.

Rosen, J. M., S. J. Altmass, and W. F. Evans, 1987: Balloon Borne Observations of PSCs, Frost Point, Ozone, and Nitric Acid in the North Polar Vortex, Geophys. Res. Lett. 16 (8), 791-794.

Sand, A., C. Klapise, and C. Prignet, 1990: Comparisons of Brightness Temperature from SSM/I and from Radiative Transfer Model in Presence of Rain in a North Atlantic Cyclone, Reprint Volume of the Fifth Conference on Satellite Meteorology and Oceanography, 3-7 September 1990, London, Published by American Meteorological Society, Boston, MA (in press).

Scully-Power, P., and P. Twitchell, 1975: Satellite Observations on Cloud Patterns over East-Australian Current Anticyclone Eddies, Geophys. Res. Lett. 2 (3), 117-119.

Sellers, P. J., F. G. Hall, G. Asrar, D. E. Strebel, and R. E. Murphey, 1988: The First SLSCP Field Experiment (FIFE), Bull. Amer. Meteor. Soc., 69 (1), 22-27.

Shapiro, M. A., L. S. Fedor, and T. Hampel, 1987: Research Aircraft Measurements of a Polar Low over the Norwegian Sea, Tellus, 39A, 272-306.

Shenk, W. E., R. F. Adler, O. Chesters, J. Susskind, and L. Vecellini, 1985: The Rationale and Suggested Approaches for Research Geosynchronous Satellite Measurements for Severe Storms and Mesoscale Investigations, NASA Technical Memo 86185, NASA/Goddard Space Flight Center, Greenbelt, MD.

Shenk, W. E., V. E. Suomi, F. Vonbun, F. Hall, W. Esaias, and M. Maxwell, 1986: Ideas for a Future Earth Observing from Geosynchronous Orbit, Proceedings of the AMS Conference on Satellite Meteorological Remote Sensing and Applications, 13-16 May 1986, Williamsburg, VA, American Meteorological Society, Boston, MA, 508-513.

Thomas, G. E., J. J. Olivero, E. J. Jensen, W. Schroeder, and A. B. Toon, 1989: Relation Between Increasing Methane and Presence of Ice Clouds at the Mesopause, Nature, 338 (6215), 490-492.

Turco, R., A. Plumb, and E. Condon, 1990: The Airborne Arctic Stratospheric Expedition: Prologue, Geophys. Res. Lett., 17 (4), 313-316.

Twomey, S., R. Gall, and M. Leuthold, 1987: Pollution and Cloud Reflectance, Boundary Layer Meteorology, 41, 235-348.

Ulwick, J. C., 1988: Comparison of Simultaneous MST Radar and Electron Density Probe Measurements in the Polar Mesosphere, SPIE Volume 874 Nonlinear Optical Beam Manipulation, Beam Combining and Atmospheric Propagation, Society of Photo-Optical Instrumentation Engineers, Bellingham, WA, 260-267.

Warren, S. G., C. J. Hahn, and J. London, 1985: Simultaneous Occurrence of Different Cloud Types, J. Climate and Appl. Meteor., 24, 658-667.

Westwater, E. R., M. T. Decker, and A. Zacks, 1983: Ground-Based Remote-Sensing of Temperature Profiles by a Combination of Microwave Radiometry and Radar, J. Climate and Appl. Meteor., 22, 126-133.

Wielicki, B. A., 1989: Satellite Cloud Retrieval: Past, Present, Future. AMS Symposium on the Role of Clouds in Atmospheric Chemistry and Global Climate, January 1989, Anaheim, CA, American Meteorological Society, Boston, MA.

Woodbury, G. E., and W. P. McCormick, 1983: Global Distribution of Cirrus Clouds Determined from SAGE Data, Geophys. Res. Lett., 10 (12), 1180-1183.

Wylie, D., 1989: Cirrus Clouds and Their Relationship to Atmospheric Dynamics, AMS Symposium on the Role of Clouds in Atmospheric Chemistry and Global Climate, January 1989, Anaheim, CA, American Meteorological Society, Boston, MA.

## APPENDIX A

### EOS Instrument Data

EOS Instrument Data - Table 1

| Sensor | Full Title of Sensor |
|---|---|
| MODIS - N | Moderate - Resolution Imaging Spectrometer - Nadir |
| MODIS - T | Moderate - Resolution Imaging Spectrometer - Tilt |
| AIRS | Atmospheric Infrared Sounder |
| HIRIS | High - Resolution Imaging Spectrometer |
| SAR | Synthetic Aperture Radar |
| GLRS | Geoscience Laser Ranging System |
| LAWS | Laser Atmospheric Wind Sounder |
| ACRIM | Active Cavity Radiometer Irradiance Monitor |
| ALT-1 | Altimeter |
| AMSR | Advanced Microwave Scanning Radiometer |
| AMSU-A | Advanced Microwave Sounding Unit-A |
| AMSU-B | Advanced Microwave Sounding Unit-B |
| CERES-IS/A | Clouds and the Earth's Radiant Energy System |
| CERES-IS/B | Clouds and the Earth's Radiant Energy System |
| ENAC | Energetic Neutral Atom Camera |
| EOSP | Earth Observing Scanning Polarimeter |
| GGI | GPS(Global Positioning System) Geoscience Instrument |
| GOS/A | Geomagnetic Observing Station |
| GOS/B | Geomagnetic Observing Station |
| HIMSS | High-Resolution Microwave Spectrometer Sounder |
| HIRDLS | High - Resolution Dynāmics Limb Sounder |
| IPEI/A | Ionospheric Plasma and Electrodynamics Instrument |
| IPEI/B | Ionospheric Plasma and Electrodynamics Instrument |
| ITIR | Intermediate Thermal Infrared Radiometer |
| LIS | Lightning Imaging Sensor |
| MISR | Multi - Angle Imaging Spectro - Radiometer |
| MLS | Microwave Limb Sounder |
| MOPITT | Measurements of Pollution in the Troposphere |
| POEMS | Positron Electron Magnet Spectrometer |
| SAFIRE/A | Spectroscopy of the Atmosphere Using Far Infrared Emission |
| SAFIRE/B | Spectroscopy of the Atmosphere Using Far Infrared Emission |
| SAGE III | Stratospheric Aerosol and Gas Experiment III |
| SCANSCAT | Advanced Scatterometer for Studies in Meteorology & Oceanography |
| STIKSCAT | |
| SEM/A | Space Environmental Monitor |
| SEM/B | Space Environmental Monitor |
| SEM/C | Space Environmental Monitor |
| SEM/D | Space Environmental Monitor |
| SEM/E | Space Environmental Monitor |
| SOLSTICE | Solar Stellar Irradiance Comparison Experiment |
| SWIRLS | Stratospheric Wind Infrared Limb Sounder |
| TES | Tropospheric Emission Spectrometer |
| TRACER | Tropospheric Radiometer for Atmos. Chemistry & Environmental Res. |
| XIE/A | X - Ray Imaging Experiment |
| XIE/B | X - Ray Imaging Experiment |
| XIE/C | X - Ray Imaging Experiment |
| XIE/D | X - Ray Imaging Experiment |

## EOS Instrument Data - Table 2

| Sensor | Phenomena to be Observed |
|---|---|
| MODIS - N | Biological and physical processes |
| MODIS - T | Bio and phys processes(emph on ocean productivity) |
| AIRS | Temp and H20 profiles, surface and cloud processes, atmos. chem. |
| HIRIS | Geological, biological and other processes |
| SAR | Land, vegetation, ice and ocean processes |
| GLRS | Seismic displacement, altimetry, aerosols and cloud top |
| LAWS | Wind vector |
| ACRIM | Total solar irradiance |
| ALT-1 | Sea surface altimetry, srfc wind speed, wave hght |
| AMSR | Water vapor, precip, sea ice, snow cover and sea surface temp & wind |
| AMSU-A | Temperature profile |
| AMSU-B | Water - vapor profile |
| CERES-IS/A | Radiation budget, cloud coverage & altitude, liquid H20 content |
| CERES-IS/B | Radiation budget, cloud coverage & altitude, liquid H20 content |
| ENAC | Energetic neutral atoms (H, He, O) > 20 keV |
| EOSP | Cloud properties(optical thickness, phase), aerosols(opt. thickness) |
| GGI | Location, temp, pres, seismic movement, total electron content |
| GOS/A | Magnetic vector field, properties of fluids in Earth's core |
| GOS/B | Magnetic vector field, properties of fluids in Earth's core |
| HIMSS | SST, ice, snow, temp, cloud and water vap content |
| HIRDLS | Chem and aerosols (O3,H20,CH4,N20,HNO3,NO2,HNO3,N2O5,CFC11,CFC12) |
| IPEI/A | Ion drift of H+, He+ and O+ in range of 10 to 5,000 m/s |
| IPEI/B | Ion concentration in range of 1-5e6 cm-3 |
| ITIR | Parameters for non-renewable resources |
| LIS | Lightning |
| MISR | Aerosols, bio-activity, cloud patterns, atmos. optical properties |
| MLS | Chemical species involved in O3 reactions at heights of 15 - 100 km |
| MOPITT | Carbon monoxide |
| POEMS | atomic and subatomic particles and gamma rays |
| SAFIRE/A | ozone layer chem(N2O5, H20 and other species with H, O and Cl) |
| SAFIRE/B | temp, ozone layer chem(CO2, HNO3, CH4, NO2, O3, N2O5) |
| SAGE III | O3, H2O, NO2 and NO3 conc, aerosols, atmos. density, & cloud data |
| SCANSCAT | Wind velocity, stress and divergence at ocean surface |
| STIKSCAT | Wind velocity, stress and divergence at ocean surface |
| SEM/A | Energetic solar particles |
| SEM/B | Low energy electons and positive ions (.05 - 20 Kev) |
| SEM/C | Ionospheric level electric field vector |
| SEM/D | Vector magnetic fields (+/- 50,000 nT) |
| SEM/E | Ionospheric total electron content |
| SOLSTICE | Solar irradiance |
| SWIRLS | Wind velocity, temp., pres., and mixing ratios of N2O and O3 |
| TES | chem conc(O3, CO, CO2, N2O, HOx, NOy, SOx, halogens, hydrocarbons) |
| TRACER | Composition of CO, CH4 and N2O |
| XIE/A | X-rays |
| XIE/B | X-rays |
| XIE/C | Electrons and protons (few eV to 20 keV) |
| XIE/D | Electrons (20 - 450 keV) and protons ( 20 keV - hundreds of MeV) |

EOS Instrument Data - Table 3

| Sensor | Swath Width |
|---|---|
| MODIS - N | 2330 km |
| MODIS - T | 1500 km |
| AIRS | 1600 km (est) |
| HIRIS | 24 km, pointing |
| SAR | 30 - 500 km |
| GLRS | 80 - 280 m, pointing |
| LAWS | 1800 km (est, 830 km altitude) |
| ACRIM | N/A |
| ALT-1 | 2 - 10 (wave height dependent) |
| AMSR | 1400 km |
| AMSU-A | 1500 km |
| AMSU-B | 1500 km |
| CERES-IS/A | cross track, limb to limb |
| CERES-IS/B | rotating, limb to limb |
| ENAC | N/A |
| EOSP | cross track, limb to limb |
| GGI | N/A |
| GOS/A | N/A |
| GOS/B | N/A |
| HIMSS | 1800 km (est) |
| HIRDLS | 2,000-3,000 km, cross track at limb |
| IPEI/A | N/A |
| IPEI/B | N/A |
| ITIR | 60 km |
| LIS | 550 km, staring array |
| MISR | 204 - 408 km cross track |
| MLS | 3.0 km, limb (20 km hor FOV) |
| MOPITT | 700 km, cross |
| POEMS | N/A |
| SAFIRE/A | 170 km, limb |
| SAFIRE/B | 120 km, limb |
| SAGE III | 90 km, limb |
| SCANSCAT | 1,600 km |
| STIKSCAT | 2, 550 km swaths with a 325 km gap |
| SEM/A | N/A |
| SEM/B | N/A |
| SEM/C | N/A |
| SEM/D | N/A |
| SEM/E | N/A |
| SOLSTICE | N/A |
| SWIRLS | 40 km, limb |
| TES | 16 - 160 km(nadir), 30 km(limb) |
| TRACER | line |
| XIE/A | 2,100 km (est) |
| XIE/B | 2,100 (est) |
| XIE/C | N/A |
| XIE/D | N/A |

## EOS Instrument Data - Table 4

| Sensor | Spatial Resolution |
|---|---|
| MODIS - N | 0.2 - 1.0 km hor |
| MODIS - T | 1.0 km hor |
| AIRS | 15 - 50 km hor, 1 km vert |
| HIRIS | 30 m (at nadir) |
| SAR | 20 - 500 m |
| GLRS | 200m hor (clouds), 2-50 km hor (aerosols) |
| LAWS | 100 km hor, 1 km vert |
| ACRIM | N/A |
| ALT-1 | |
| AMSR | 9 - 50 km |
| AMSU-A | 50 km (hor) |
| AMSU-B | 15 km (hor) |
| CERES-IS/A | 40 km |
| CERES-IS/B | 40 km |
| ENAC | 24 sec - temporal (6 sec for ions) |
| EOSP | 10 km hor (at nadir) |
| GGI | 1 km vertical (temperature) |
| GOS/A | |
| GOS/B | |
| HIMSS | 50 km(at 6.6GHz)-5 km(at 90GHz) |
| HIRDLS | 400km hor, 1 km vert |
| IPEI/A | <= 1 sec (temporal) |
| IPEI/B | |
| ITIR | 15 - 90 m |
| LIS | 10 km hor, 1 ms temporal |
| MISR | 240 - 1.92 km |
| MLS | 300km along, 2.5 km vert |
| MOPITT | 22 km hor, 3 km vert |
| POEMS | |
| SAFIRE/A | 3.0 km vertical, 1 - 5 degrees lat, 25 de |
| SAFIRE/B | 1.5 km vertical, 1 - 5 degrees lat, 25 de |
| SAGE III | 1 - 2 km vert |
| SCANSCAT | 25 km hor |
| STIKSCAT | 25 km hor |
| SEM/A | |
| SEM/B | |
| SEM/C | |
| SEM/D | |
| SEM/E | |
| SOLSTICE | |
| SWIRLS | 3 km vert,200 km cross,350km along track |
| TES | 0.5 - 5 km (cross), 5 - 50 km (along), 2. |
| TRACER | 3 km vert, 300 km cross, 20 km along |
| XIE/A | 41 - 243 km hor |
| XIE/B | 41 - 243 km hor |
| XIE/C | |
| XIE/D | |

EOS Instrument Data - Table 5

| Sensor | Data Rate (kbits/s) | Volume of Data for Data Levels 0; 1; 2 (Mbits/day) |
|---|---|---|
| MODIS - N | 11,400 - 15,000 | |
| MODIS - T | 1,400 - 3,500 | |
| AIRS | 1,500 | |
| HIRIS | 3,000 - 100,000 | |
| SAR | 15,000 - 180,000 | |
| GLRS | 500 - 1,000 | 800 |
| LAWS | 1,500 | |
| ACRIM | .5 | 35.2; .8; |
| ALT-1 | | 80 |
| AMSR | 50 | 4,300; ; |
| AMSU-A | 6.5 | 432; ; (total for AMSU) |
| AMSU-B | 4.2 | 432; ; (total for AMSU) |
| CERES-IS/A | 10 (total for CERES) | 320; ; (total for CERES) |
| CERES-IS/B | 10 (total for CERES) | 320; ; (total for CERES) |
| ENAC | 5 | 580; 1,000; 26 |
| EOSP | 45 - 90 | 3,800; 4,000; 2,900 |
| GGI | 50 | ; 9,000; 1,500 |
| GOS/A | 8 (total for GOS) | 720; 2,500; 560 |
| GOS/B | 8 (total for GOS) | 720; 2,500; 560 |
| HIMSS | 44 | 2,300; 2,700; 1,800 |
| HIRDLS | 15 | |
| IPEI/A | 1.1 (total for IPEI) | |
| IPEI/B | 1.1 (total for IPEI) | |
| ITIR | 12,700 - 88,000 | 717,120; ; |
| LIS | .5 - 3.0 | |
| MISR | 70 - 3,600 | ; 30,200; 700 |
| MLS | 1,000 | ; 16,000; 160 |
| MOPITT | 1 | 86.4; 20.8; 41.6 |
| POEMS | 13 - 600 | |
| SAFIRE/A | 9,000 total for A&B | ; 722,000; 24.6 |
| SAFIRE/B | 9,000 total for A&B | ; 722; 17.2 |
| SAGE III | 15 - 82 K | 700; 140; 50 |
| SCANSCAT | 50 | |
| STIKSCAT | | |
| SEM/A | 4 (total for SEM) | 350.4; ; (total for SEM) |
| SEM/B | 4 (total for SEM) | 350.4; ; (total for SEM) |
| SEM/C | 4 (total for SEM) | 350.4; ; (total for SEM) |
| SEM/D | 4 (total for SEM) | 350.4; ; (total for SEM) |
| SEM/E | 4 (total for SEM) | 350.4; ; (total for SEM) |
| SOLSTICE | 5 - 8 | 432 - 696; 561; .04 |
| SWIRLS | 0.2130 | 86.4; 101.6; 9.6 |
| TES | 80 - 13,500 | 9,000 - 31,000; ; (per orbit) |
| TRACER | 10 | 869; 1,850; 2,450 |
| XIE/A | 17-34(total for XIE) | 2,000 (total for XIE & data levels) |
| XIE/B | 17-34(total for XIE) | 2,000 (total for XIE & data levels) |
| XIE/C | 17-34(total for XIE) | 2,000 (total for XIE & data levels) |
| XIE/D | 17-34(total for XIE) | 2,000 (total for XIE & data levels) |

EOS Instrument Data - Table 6

| Sensor | Lines of Code to Process to Level 1; 1-2 | Required CPU Resources to Process Data to Level 1; 1 to 2 |
|---|---|---|
| MODIS - N | | |
| MODIS - T | | |
| AIRS | | |
| HIRIS | | |
| SAR | | |
| GLRS | | |
| LAWS | | |
| ACRIM | | |
| ALT-1 | | |
| AMSR | | |
| AMSU-A | | |
| AMSU-B | | |
| CERES-IS/A | 55; 95 k | 16; 1300 G op / day |
| CERES-IS/B | 55; 95 k | 16; 1300 G op / day |
| ENAC | | 75; M mult /day |
| EOSP | ; 200 | |
| GGI | 17; 196 k | 3.6; 32.5 Mflops |
| GOS/A | 50 k (to level 2) | 60min CPU on NAS 8050 (total) |
| GOS/B | 50 k (to level 2) | 60min CPU on NAS 8050 (total) |
| HIMSS | 18 k (to level 2) | 10 MIPS (to level 2) |
| HIRDLS | | |
| IPEI/A | | |
| IPEI/B | | |
| ITIR | | |
| LIS | | |
| MISR | | |
| MLS | 5 ; 10 k | 2; 1 Mflops |
| MOPITT | | 585; 10,350 M op / day |
| POEMS | | |
| SAFIRE/A | 2; 6 k | 19; 23 Mflops |
| SAFIRE/B | 4; 6 k | .01; .04 Mflops |
| SAGE III | 40; 20 k | 19; 10 G op / day |
| SCANSCAT | | |
| STIKSCAT | | |
| SEM/A | | |
| SEM/B | | |
| SEM/C | | |
| SEM/D | | |
| SEM/E | | |
| SOLSTICE | 12; 1 k | |
| SWIRLS | 20 k (to level 2) | |
| TES | 15; 100 k | 500 Mflops (total) |
| TRACER | 44; 31 k | 32; 30 G op / day |
| XIE/A | | |
| XIE/B | | |
| XIE/C | | |
| XIE/D | | |

EOS Instrument Data - Table 7

| Sensor | No. Channels | Freq/Wvlgth |
| --- | --- | --- |
| MODIS - N | 36 | 0.47 - 2.13/3.7 - 4.56/6.7 - 14.54 um |
| MODIS - T | 64 | 0.41 - .875 um |
| AIRS | 115 - 4,000 | .4 - 1.1 / 3.4 - 17.0 um |
| HIRIS | 192 | 0.4 - 2.45 um |
| SAR | 3 | 1.248(L), 5.298(C), 9.6(X) GHz |
| GLRS | 3 | 1,064, 532 and 355 nm |
| LAWS | 1 | 9.11 um |
| ACRIM | | |
| ALT-1 | 2 | 5.3 and 13.6 GHz |
| AMSR | 5 | 6.6, 10.65, 18.7, 23.8 and 31.55 GHz |
| AMSU-A | 15 | 23.8, 31.4, 50.3 - 57.3 and 89 GHz |
| AMSU-B | 5 | 89, 157 and 183.31 GHz |
| CERES-IS/A | 3 | .2 - 100 / .2 - 3.5 / 6 - 25 um |
| CERES-IS/B | 3 | .2 - 100 / .2 - 3.5 / 6 - 25 um |
| ENAC | | |
| EOSP | 12 | 410 - 2,250 nm |
| GGI | 18 | |
| GOS/A | | |
| GOS/B | | |
| HIMSS | 19 | 6.6 - 90.0 GHz |
| HIRDLS | 11 | 6.08 - 17.99 um |
| IPEI/A | | |
| IPEI/B | | |
| ITIR | 14 | .52 - .86/1.60 - 2.43/8.025 - 11.65 um |
| LIS | 1 | 777.4 nm |
| MISR | 4 | 440, 550, 670 and 860 nm |
| MLS | 5 | 637, 560, 205, 117 and 270 |
| MOPITT | 4 | near 2,140 and 4,100 cm-1 |
| POEMS | | |
| SAFIRE/A | 7 | 25 - 35 / 62.5 - 125 um |
| SAFIRE/B | 7 | 6 - 17 um |
| SAGE III | 9 | 290 - 1550 nm |
| SCANSCAT | 1 | 13.995 GHz |
| STIKSCAT | 1 | 13.995 GHz |
| SEM/A | | |
| SEM/B | | |
| SEM/C | | |
| SEM/D | | |
| SEM/E | | |
| SOLSTICE | 4 | 115 - 440 nm |
| SWIRLS | 6 | 7.6 - 17.2 um |
| TES | | 2.9 - 16.6 um |
| TRACER | 2 | 2.3 and 4.6 um |
| XIE/A | | 3 - 20 keV |
| XIE/B | | 20 - 200 keV |
| XIE/C | | |
| XIE/D | | |

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16. Abstract

To advance understanding of the Earth system requires improved knowledge of the time variant governing processes, and the knowledge of these processes often only comes from real time observations of the changing variables as seen from space. The unpredictability of what is to be measured and at what rate requires flexibility in the observational capability. The Earth Observing System (EOS) will be a major source of observational data during the next 10- to 25-year timeframe. Consequently, to ensure the needed advances in the understanding of the Earth system, real time onboard processing is concluded to be a critical need for EOS.

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